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Stock assessment of northern gemfish (*Rexea solandri*) in SKI 1 and SKI 2 for the 2001–02 fishing year

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1. EXECUTIVE SUMMARY

Dunn, A.; Hurst, R.J.; Phillips, N.L. (2001). Stock assessment of northern gemfish (*Rexea solandri*) in SKI 1 and SKI 2 for the 2001–02 fishing year.

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Northern (SKI 1 and SKI 2) gemfish (*Rexea solandri*) catches increased during the 1980s and to between 2000 and 2300 t from 1988–89 to 1994–95. The Total Allowable Catch (TAC) also increased during this period to the maximum of 2452 t in 1993–94. Catches declined to below 70% of the combined TAC in 1995–96, and continued to decline until 1998–99. The combined TAC was reduced in 1997–98 (1601 t), and again in 1998–99 (980 t), but was still under-caught by 25% in 1998–99. In 1999–2000, catches increased slightly but were still below the TAC for that year.

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 & 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. Age frequency data for 1996–97 to 1998–99 for SKI 1E and SKI 1W were similar and show no evidence of a separate stock in the newer SKI 1W fishery.

Most of the reported catch was target fished on both the non-spawning fish in SKI 2 and spawning run fish in SKI 1. Standardised catch-per-unit-effort (CPUE) indices show large declines for both of the fisheries since 1989–90, with current CPUE indices at about 12–13% of 1989–90 levels.

For this assessment, all relevant biological parameters, commercial catch history, CPUE, and commercial catch-at-age data were incorporated into a single age and sex structured population model fitted using MIAEL estimation methods (as used in the 1997 to 2000 assessments). Least squares sum of residuals, MIAEL estimates of virgin biomass and current biomass, and sustainable yields were obtained. The results from the stock model suggest that the fish stock has declined since 1990 to about 16% of virgin biomass, well below the estimated level of B_{MSY}. Single year projections suggest that the stock may continue to decline further (to 11%), even assuming average recruitment in recent years. The assessment is not particularly sensitive to changes in the bounds for minimum and maximum exploitation. It is slightly more positive when natural mortality is assumed to be high (i.e., projected biomass declines from 16 to 13%); and more negative (i.e., projected biomass declines from 15 to 8%) when more recent (1996 and 1997) year class strengths are estimated. The MIAEL estimates of current stock status had high performance indices (over 70%), but estimates of virgin and current biomass were less certain.

Residual analyses from the stock model suggested evidence of undesirable structure within the model fits. In particular, residual analysis for the catch-at-age data for SKI 1 and the CPUE indices for SKI 2 suggested that fits to these time series could be improved. Sensitivity tests where parameters for year class strengths, home ground fishing selectivity ogives, or maturity ogives were estimated within the model did not appear to resolve these problems.

1. INTRODUCTION

1.1 Overview

The gemfish fishery in New Zealand is managed as three separate fish stocks: Quota Management Areas (QMAs) SKI 1 & 2, SKI 3 & 7, and SKI 10. However, gemfish were modelled as two stocks: northern (comprising the Quota Management Areas (QMAs) SKI 1 & 2) and southern (QMAs SKI 3 & 7). Figure 1 shows the Fishery Management Areas (FMAs), and the northern (SKI 1 & 2) and southern (SKI 3 & 7) QMA stock boundaries. In this report, we defined SKI 1W as that part of SKI 1 comprising FMA 9, and SKI 1E as that comprising FMA 2.

This paper reviews the commercial fishery for gemfish in 1999–2000 and describes the stock assessment model for the northern stock, including the model input data and model structure.

Model input data presented here include: commercial catches, split into non-spawning season (SKI 2) and spawning season (SKI 1); CPUE time series for SKI 1 and SKI 2 from 1989 to 2000; age frequency time series from commercial catches for SKI 1 and SKI 2 (derived from SKI 1E, winter 1989 to 1994, 1997 to 1999; SKI 1W, winter 1996 to 1999; SKI 2, fishing years 1995–96 to 1999–2000).

This report fulfils objectives 1 and 2 of the Ministry of Fisheries research contract MOF2000/03D to (1) update the SKI 1 and SKI 2 standardised CPUE analyses in 2001 by the inclusion of data up to the end of the 1999–2000 fishing year, and (2) update the stock assessment for gemfish (SKI 1 & 2), including estimation of biomass and sustainable yields.

1.2 Literature review

Gemfish are an important Australian fishery and there are numerous published reports on its biology and fishery. Rowling (1994) reviewed the southeast fishery for gemfish, including data from unpublished reports. Key published references are: Colgan & Paxton (1997) on stock structure; Lyle & Ford (1993) on reproductive biology; Withell & Wankowski (1989), Rowling (1990) and Rowling & Reid (1992) on age and growth; Rowling (1994) and Tilzey et al. (1990) on the gemfish fishery.

In 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 (Ingerson & Colman 1997, Langley 1995); 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), 1999 (Hurst et al. 1999b), and 2000 (Hurst et al. 2000); age validation and a review of stock structure of New Zealand gemfish (Horn & Hurst 1999); and the influence of ocean climate on southern gemfish recruitment patterns (Renwick et al. 1998) and northern gemfish recruitment patterns (Hurst et al. 1999a). Development of combined CPUE models for SKI 1 (areas SKI 1E and SKI 1W) and SKI 2 (midwater and bottom trawl methods) were also reported by Hurst et al. (1999a) and Hurst et al. (2000).

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 R.V. *Kaharoa*, which sampled juvenile gemfish (Kirk & Stevenson 1996, Stevenson 1996a, 1996b, Stevenson & Kirk 1996). These were reviewed by Stevenson & Hanchet (2000). Hurst & Bagley (1998) listed reports relevant to the southern gemfish stock.

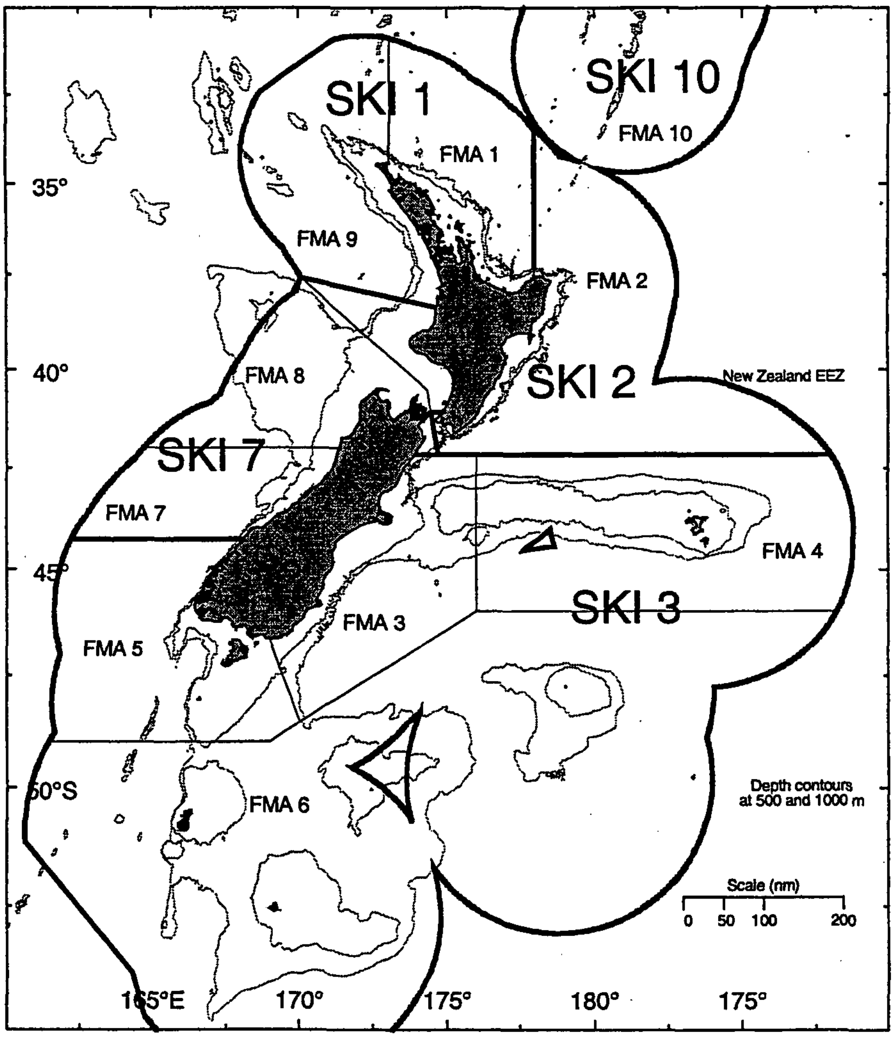

Figure 1: Fishery Management Areas (FMAs) and the Quota Management Areas (QMAs) for gemfish in the New Zealand EEZ. The northern stock comprises QMAs SKI 1 & 2; the southern stock comprises QMAs SKI 3 & 7.

2. REVIEW OF THE FISHERY

2.1 Annual catches

Holton (1987) and 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 — although gemfish were 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 as activity in gemfish areas appeared to have been minimal.

On 1 March 1978, the 200 nautical 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 1985–86, catches were unrestrained and peaked at 8011 t in 1985–86, of which most was caught in southern waters (Table 1).

The gemfish fisheries in northern waters (SKI 1 & 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 the 2000–01 and 2001–02 fishing years were assumed based on the TAC for 2000–01.

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

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

1. 1 April – 31 March
2. 1 April – 30 September
3. 1 October – 30 September
4. 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 fish stock from 1983–84 to 1996–97 and TACs for 1986–87 to 1999–2000.

Fish stock	SKI 1		SKI 2		SKI 3		SKI 7		SKI 10		Total	
	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1983–84[1]	588	–	632	–	3 481	–	1 741	–	0	–	6 442[3]	–
1984–85[1]	388	–	381	–	2 533	–	1 491	–	0	–	4 793[3]	–
1985–86[1]	716	–	381	–	5 446	–	1 468	–	0	–	8 011[3]	–
1986–87[2]	773	550	896	860	2 045	2 840	1 069	1 490	0	10	4 783	5 750
1987–88[2]	696	632	1 095	954	1 664	2 852	1 073	1 543	0	10	4 528	5 991
1988–89[2]	1 023	1 139	1 011	1 179	1 126	2 922	1 083	1 577	0	10	4 243	6 827
1989–90[2]	1 230	1 152	1 043	1 188	1 164	3 259	932	1 609	0	10	4 369	7 218
1990–91[2]	1 058	1 152	949	1 188	616	3 339	325	1 653	0	10	2 948	7 342
1991–92[2]	1 017	1 152	1 208	1 197	287	3 339	584	1 653	0	10	3 096	7 350
1992–93[2]	1 292	1 152	1 020	1 230	371	3 345	469	1 663	0	10	3 152	7 401
1993–94[2]	1 156	1 152	1 058	1 300	75	3 345	321	1 663	0	10	2 616	7 470
1994–95[2]	1 031	1 152	905	1 300	160	3 355	103	1 663	0	10	2 215	7 480
1995–96[2]	801	1 152	789	1 300	49	3 355	81	1 663	0	10	1 720	7 480
1996–97[2]	965	1 152	978	1 300	58	1 500	238	900	0	10	2 240	4 862
1997–98[2]	627	752	671	849	27	300	44	300	0	10	1 369	2 211
1998–99[2]	413	460	335	520	17	300	59	300	0	10	824	1 590
1999–2000[2]	409	460	506	520	62	300	107	300	0	10	1 083	1 590

1. FSU data
2. QMS data
3. The totals do not match those in Table 1, as some of the catch was not reported by area (FSU data before 1986–87).

Table 3: Spawning (SKI 1) and non-spawning (SKI 2) catch (t) of gemfish.

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	409	506
1976	30	190	2001[1]	460	520

1. Assumed catch based on TAC for 2000–01

2.2 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 respectively. The TACs 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 TACs for SKI 1 and SKI 2 were 753 and 850 t. They were further reduced to 460 and 520 t for 1998–99, where they have since remained.

2.3 Catch effort data

Catch effort data from Catch Effort Landing Returns (CELR) and Trawl Catch Effort Processing Returns (TCEPR) were used to generate standardised catch-per-unit-effort (CPUE) indices for northern gemfish fisheries. The standardised CPUE analyses of these fisheries are presented as Appendix C, and summarised in Table 4. These update the CPUE models developed in 2000 (Hurst et al. 2000), providing combined area indices for SKI 1 E & W and combined (midwater and bottom trawl) indices for SKI 2. Note that the estimated value of the index for 1999 for SKI 2 differs more than would be expected from values previously reported (i.e., 0.07 in 1999). This was due to a calculation error in the CPUE indices reported by Hurst et al. (2000).

Table 4: Estimated CPUE indices with 95% confidence intervals for SKI 1 & 2 from 1990 to 2000.

	SKI 1		SKI 2	
Year	Index	95% C.I.	Index	95% C.I.
1990	1.00	na	1.00	na
1991	0.94	0.75–1.19	0.74	0.55–1.00
1992	0.38	0.30–0.48	0.53	0.41–0.70
1993	0.51	0.41–0.64	0.29	0.23–0.38
1994	0.43	0.34–0.55	0.24	0.19–0.32
1995	0.27	0.21–0.35	0.14	0.10–0.19
1996	0.18	0.14–0.23	0.14	0.10–0.19
1997	0.26	0.20–0.32	0.13	0.10–0.18
1998	0.15	0.12–0.20	0.07	0.05–0.10
1999	0.17	0.13–0.23	0.11	0.07–0.15
2000	0.13	0.10–0.19	0.12	0.09–0.18

2.4 Size and age composition of commercial catches

Otoliths and length frequency data were 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 1999–2000.

2.4.1 Length frequency data

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 was undertaken 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 B1–B3 of Appendix B. Catch sampling of SKI 2 in 1999–2000 was carried out under Ministry of Fisheries project INS1999/01. Length frequencies for SKI 2 for 1999–2000 are given in Figure B1 of Appendix B.

2.4.2 Age frequency data

The time series of otoliths were aged using the technique developed by Horn & Hurst (1999). A separate age-length key was derived for each sex, fishery area, and year, and applied to the scaled length frequency to determine the age frequency. The resulting proportions at age, by sex, are given in Tables B4–B6 and Figures B2–B4 in Appendix B. Age data for SKI 1E & 1W were combined for the stock assessment model. The estimated proportions at age used for the stock models are given in Table B7 of Appendix B.

The SKI 1E time series included nine years of data and indicated that relatively strong year classes were spawned in 1980, 1982, 1984, and 1991 (Figure 2). The strong 1980 year class had almost completely disappeared from the age frequencies by 1998. The later strong year classes were also apparent in the age frequencies for SKI 1W (Figure 3) 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 from a separate stock than SKI 1E, then the age frequency would have been expected to show a greater proportion of older fish that had been subjected to lower exploitation.

A breakdown of age frequency by fishing method (midwater or bottom trawl) in SKI 2 did not show any major differences and so the previous approach of combining all data for SKI 2 was continued (see Hurst et al. 1999b, appendix 2). The age frequencies for SKI 2 (Figure 4) showed 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 was because the fishery is on non-spawning fish. The SKI 2 fishery is on non-spawning fish and included a greater proportion of young fish that were immature, while the SKI 1 fisheries are on adults migrating to spawn. Here, the fish are not fully recruited into the fishery until about age 7 to 9 (see later).

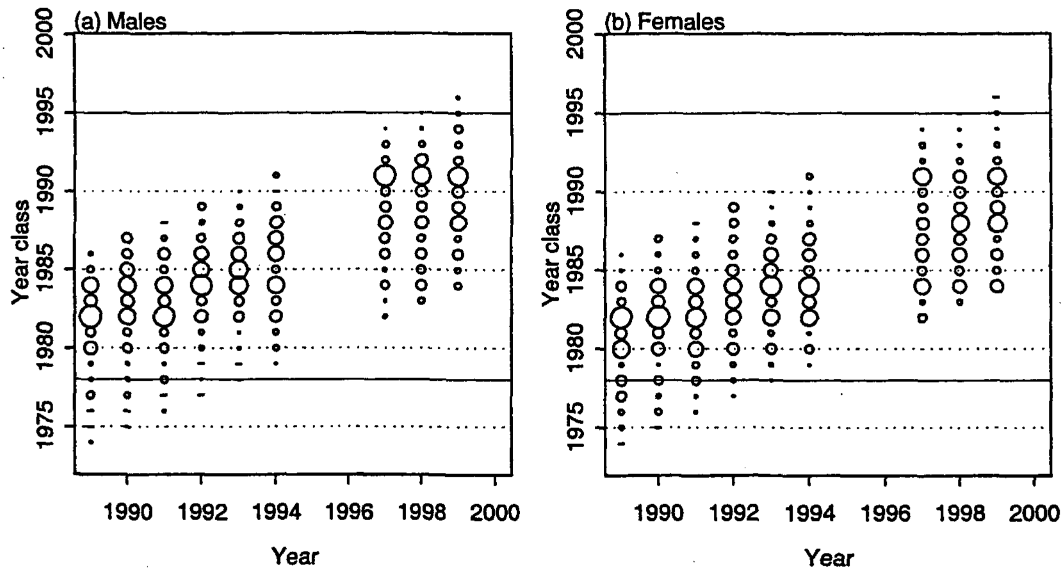

Figure 2: Age frequencies (ages 3 to 15) by year class and year (symbol area proportional to the proportions at age within sampling event) from the SKI 1E shed sampling for (a) males, and (b) females. Zero values are represented by a dash, and horizontal lines indicate the earliest (1978) and latest (1995) year class strengths estimated in the (base case) stock assessment model.

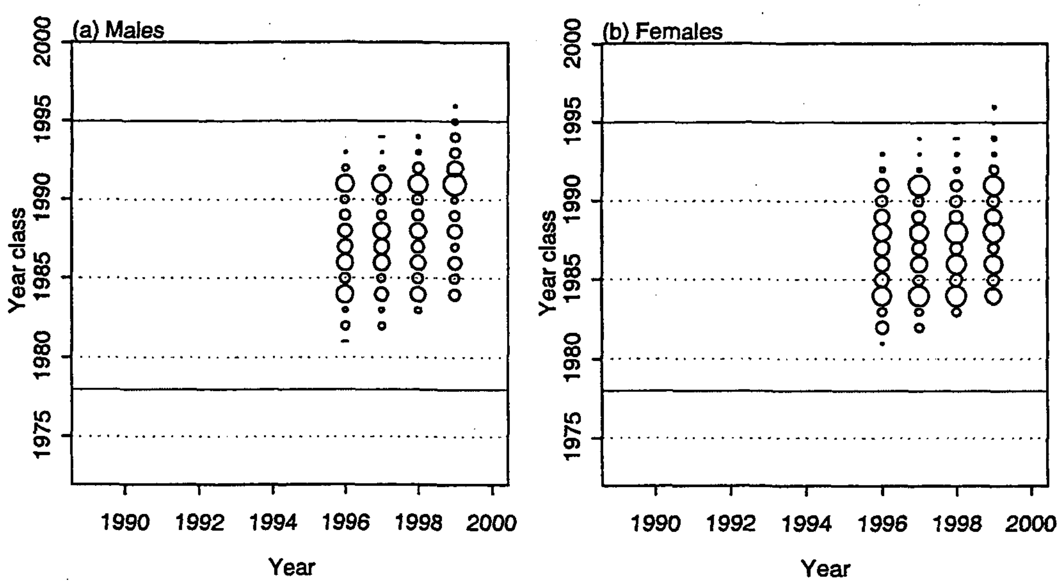

Figure 3: Age frequencies (ages 3 to 15) by year class and year (symbol area proportional to the proportions at age within sampling event) from the SKI 1W shed sampling for (a) males, and (b) females. Zero values are represented by a dash, and horizontal lines indicate the earliest (1978) and latest (1995) year class strengths estimated in the (base case) stock assessment model. (Note that year classes have been presented so as to make them comparable to the SKI age data by assigning the upcoming birthday.)

Age frequency data were combined for SKI 1E and 1W and proportions at age (Table B7, Appendix B) were determined for input to the model. Both sexes combined sum to 1.0 for each year. The SKI 2 proportions at age enter into the model as pre-spawning, and have not been assigned the birthday for the fishing year in which they were sampled. However, aside from the table of model input data (Table B7), plots and tables of proportions at age have been assigned a birthday so that the data for SKI 1 and SKI 2 are comparable. Age data are assigned a c.v. of 0.35 in models, weighted by the number of samples per year (see also Table B7, Appendix B).

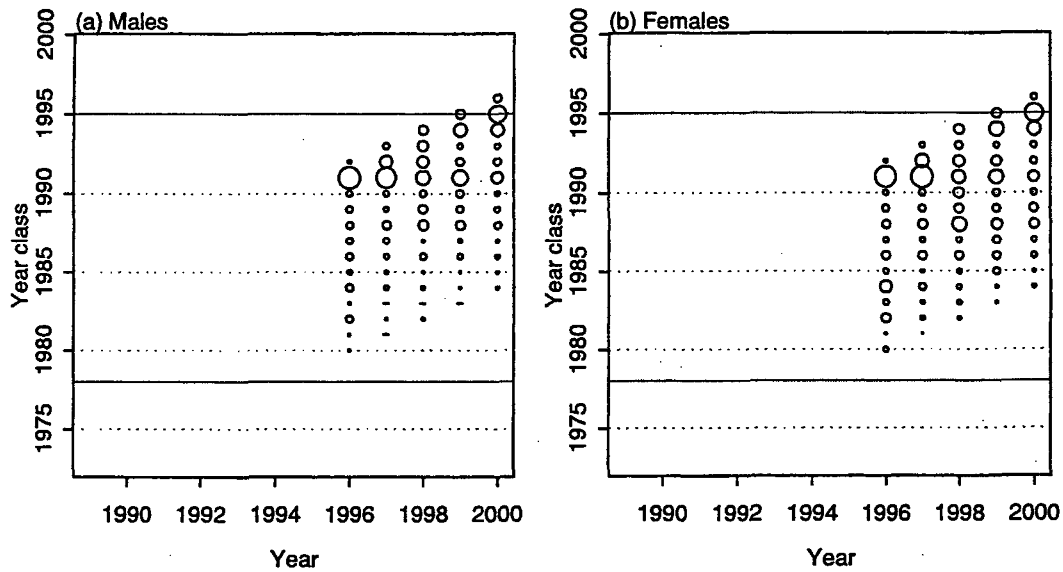

Figure 4: Age frequencies (ages 3 to 15) by year class and year (symbol area proportional to the proportions at age within sampling event) from the SKI 2 shed sampling for (a) males, and (b) females. Zero values are represented by a dash, and horizontal lines indicate the earliest (1978) and latest (1995) year class strengths estimated in the (base case) stock assessment model.

2.5 Recreational fisheries

There were no recreational catches of gemfish 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 was a target recreational fishery in the Bay of Plenty. Reported gemfish catch in the North region recreational survey for 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 & 2, and fewer than 500 fish from SKI 7.

2.6 Maori customary fisheries

Quantitative information on the current level of Maori customary take is not available, and was assumed to be negligible in the stock model.

2.7 Illegal catch

The amount of gemfish misreported is not available and was assumed to be negligible in the stock model.

2.8 Other sources of mortality

There may have been some gemfish discarded before the introduction of the EEZ. However, the level of discard was 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 bycatch 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 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 described.

3.1 Stock structure

The relationship between SKI 1E, SKI 1W, and SKI 2 for northern gemfish remains uncertain. The SKI 1 and SKI 2 fisheries continue to shown the same seasonal patterns as found by Hurst (1988). In SKI 1, about 70% of the catch are taken in May and June. In SKI 2, catches were spread throughout the year, except for an almost zero catch during the winter in June to August (Hurst et al. 1998). Localised fishing patterns suggested 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 were recorded only from SKI 1 and the distribution of young fish (15–30 cm, 6–12 months old) was quite localised and consistent with the distribution of ripe females (see Hurst & Bagley 1998, figures 24 & 25)

The age and length frequency data (see Section 2.4) show similar patterns of strong year classes for 1980, 1982, 1984, and 1991 (where the series overlap) and provide support for the hypothesis of a single stock in SKI 1 and 2.

Horn & Hurst (1999) derived von Bertalanffy growth parameters (von Bertalanffy 1957) for northern gemfish from the age-length data from the commercial fisheries, as well as length frequency data for juvenile fish from trawl surveys off the Wairarapa coast (Table 5). Comparison of the von Bertalanffy parameters calculated for the different areas using the combined otolith and length-based data sets showed some significant between-sample differences in the L_∞ and k parameters, but these were not consistent between either area or sex.

Table 5: 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.

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

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.

The length weight relationship that was assumed for gemfish (Langley et al. 1993) is shown in Table 6.

Table 6: Estimated length weight relationship for gemfish, where *weight* = *a(length)*^{b} with *weight* in grams and *length* in centimetres.

Sex	Parameter estimate	
Males	$a = 0.001$	$b = 3.55$
Females	$a = 0.003$	$b = 3.22$

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 hypothesis 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 fishery in recent years indicated an A_{max} (i.e., the age reached by 1% of the population) of about 15 years for males and 16 years for females (Horn & Hurst 1999).

A range of estimates of natural mortality (M) can be derived from the equation (Hoenig 1983),

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

where A_{max} is the age reached by some proportion (1%) of the virgin population (Sparre & Venema 1992).

A maximum age of 15 in the current population produces an estimate of M of about 0.3 y^{-1}. As the samples were clearly not from virgin populations, it seems likely that M for gemfish is in the range 0.2–0.3 y^{-1}, with the current assumption being 0.25 y^{-1}.

3.3 Trawl survey biomass estimates

Biomass estimates are available for northern gemfish from SKI 2 from four east coast North Island trawl surveys (1993, 1994, 1995, and 1996) by R.V. *Kaharoa* (Stevenson & Hanchet 2000). These surveys sampled to a depth of about 400 m, hence some gemfish may have been missed, as they are known to occur in deeper waters (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. Therefore, the biomass estimates were not used in the stock assessment modelling. However, the surveys probably did adequately sample younger age classes (up to about age 4) and these data have been used to determine the length-at-age of northern juvenile gemfish (Horn & Hurst 1999).

4. MODEL STRUCTURE AND BIOMASS ESTIMATES

The stock model and the MIAEL estimation procedure used for northern gemfish was similar to that used for the 1997 (Annala & Sullivan 1997), 1998 (Hurst et al. 1998), 1999 (Hurst et al. 1999b), and 2000 (Hurst et al. 2000) stock assessments. The stock model was an age-structured, two-sex population model (see Cordue 1993, 1995, 1998a, 1998b, 1998c) with separate spawning and non-spawning fishing grounds.

4.1 Model input data

The pre-spawning (SKI 2) and spawning season (SKI 1) catches used in the modelling are given in Table 3. Catches for 2001 were assumed to be at the level of the 2000–01 TAC for each of the two fisheries.

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 1999–2000) are given in Table B7 of Appendix B. A median c.v. of 0.35 (unless indicated) was assumed for each year's age data and weighted by the number of samples per year. Ageing error applied was ± 5% from age 5. Lognormal errors were assumed. The von Bertalanffy growth parameters calculated by Horn & Hurst (1999) are given in Table 5.

Standardised CPUE indices for SKI 1 and SKI 2 are shown in Table 4. The results were based on models including vessel as a categorical variable. A c.v. of 0.35 was applied to the CPUE indices and lognormal errors were assumed.

Table 7 shows the assumed model parameters for the base case assessment and the sensitivity analyses (see below for a description of the model structure).

4.2 Model structure

Estimates of mid-season virgin biomass (B_0), 2001 mid-season biomass (B_{mid01}), and 2002 mid-season biomass (B_{mid02}) were obtained using the least squares and MIAEL estimation method of Cordue (1993, 1995, 1998a). The estimation used the single stock model, as detailed by Cordue (1998b, 1998c), implemented on a Silicon Graphics Inc. Cray T3E Massively Parallel Processing system. Minor modifications to the single stock model used for this assessment were described in detail by Cordue (2000). In brief, these consisted of introducing penalty functions to the home ground selectivity estimates (where estimated), so that the selectivities by age were encouraged to be cubic polynomials with female selectivity less than male selectivity at age. In addition, the mean of estimated relative year class strengths were encouraged so as to equal 1. Hence model function values consisted of a residual sum of squares component and a penalty value. MIAEL estimates were calculated using the `bestp` estimation method (Cordue 1995).

The modelling procedure was conducted in two steps. The first step used all of the input data to obtain least squares estimates of B_0 and year class strengths. For the base case, age at maturity, home ground (non-spawning) fishing selectivity, and spawning ground fishing selectivity ogives were assumed fixed and known (see Table A1 in Appendix A). Maturity ogives are defined as the proportion of immature fish that become mature by age. Values for these ogives were the smoothed estimates from Hurst et al. (1999b) and these were used in the base case. Biomass trajectories were determined from the least squares estimates of B_0 and associated nuisance parameters.

Relative year class strengths were estimated for the years 1978 to 1995. The most recent year for which year class strengths was to be estimated was chosen as 1995, as there were at least 3 years of observations of that year class within the proportion at age data. All other year class strengths were assumed to be 1.

Table 7: Input parameters for the base case and sensitivity analyses.

Parameter	Base	Sensitivity to Base							
		1	2	3	4	5	6	7	8
		Low M	High M	Increase MinMax	Reduce r_{max}	Estimate ogives	Extra YCS	No YCS penalty	Reduce ages
Steepness	0.9								
Recruitment variability (rsd)	1.0								
Proportion spawning	0.95								
Natural mortality M (y^{-1})	0.25	0.2	0.3						
Spawning season length	0.25								
Pre-spawning max. exploitation	0.3								
Spawning max. exploitation	0.5				0.35				
Min. exploitation with max. catch	0.01			0.03					
Maturity ogive = Fixed	Yes [1]					No			
Home ground selectivity = Fixed	Yes [1]					No			
Spawning ground selectivity = Fixed	Yes [1]								
CPUE weight (c.v.)	1.0 (0.35)								
Age weight (c.v.)	1.0 (0.35)								
Ageing error (for ages $\geq$ 3)	$\pm$ 5%								
Year class strength estimated: from	1978						1978		
to	1995						1997		
Penalty so that YCS $\approx$ 1	Yes							No	
SKI 1 catch-at-age data: male	3–15								4–13
female	3–15								4–14

1. The maturity, home ground fishing selectivity, and spawning ground fishing selectivities were assumed fixed and known (see Table A1 in Appendix A).

The second step used the MIAEL estimation procedure to calculate the MIAEL least squares estimate (MIAEL LSQ estimate) and a MIAEL estimate for B_0, B_{mid01}, and B_{mid02}. At this step, biomass indices from the CPUE index only were used, with year class strengths (previously calculated in the first step) assumed known. The model was refitted and MIAEL least square estimates of B_0, B_{mid01}, and B_{mid02} determined. MIAEL estimation was conducted on these revised least squares estimates to give the MIAEL estimates of B_0, B_{mid01}, B_{mid02}, yield estimates and performance indices.

Sensitivity analyses were run using the variations from the base case parameters. The sensitivity analyses and associated assumptions are listed in Table 7. These consisted of sensitivities for lower and higher values of natural mortality (M) as Sensitivity 1 and 2. Sensitivity 3 and 4 considered the arbitrary choice of B_{min} and B_{max} bounds by increasing the minimum exploitation at the time of the maximum catch and decreasing maximum exploitation of the spawning fishery rates respectively. Sensitivity 5 estimated (smoothed) ogives for the home ground fishing selectivity and the maturity ogive; the spawning fishing selectivity was still assumed to be 1 (see Tables A1 and A2, Appendix A). Sensitivity 6 included estimation of year class strengths for 1996 and 1997. Because there were only a few observations for these years, the model estimated these values with low precision. The penalty to encourage estimated year class strengths to approximate 1 was removed for Sensitivity 7. Structure within the residuals for the catch-at-age data for SKI 1 suggested that low values may have adversely affected model fits. The age data for SKI 1 was modified to exclude those fish aged 3, 14, and 15 for males, and ages 3 and 15 for females (Sensitivity 8).

4.3 Biomass estimates

Table 8 shows the least squares values (from the first step of the estimation), and resulting function value, for each model. The function value was made up from two components, the sum of squares of fits to the input data, and penalty contributions. Penalties were from four sources; the B_{min} and B_{max} bounds, ensuring that the year class strengths averaged about 1, smoothed (cubic) fits to the estimated ogive (where these were estimated), and ensuring that for each (estimated) ogive, that female selectivity was less than male selectivity by age.

Table 8: Least squares estimates (LSQ) of B_0, residual sum of squares (SSQ), penalty sum of squares, and total model function value for the base cases and the sensitivity analyses.

		Function value		
Sensitivity	LSQ	SSQ	Penalty	Total
Base	12 495	11.54	0.05	11.59
Sensitivity 1 (Low *M*)	13 163	11.94	0.07	12.01
Sensitivity 2 (High *M*)	12 988	11.26	0.04	11.30
Sensitivity 3 (Increase MinMax)	12 495	11.54	0.05	11.59
Sensitivity 4 (Reduce r_{max})	12 495	11.54	0.05	11.59
Sensitivity 5 (Estimate ogives)	11 676	11.47	0.37	11.84
Sensitivity 6 (Extra YCS)	11 612	10.82	0.02	10.84
Sensitivity 7 (No YCS penalty)	10 800	11.26	0.00	11.26
Sensitivity 8 (Reduce ages)	13 712	9.28	0.00	9.28

Year class strengths were re-estimated for each sensitivity run of the model and are shown in Table 9. All runs estimate higher recruitment in the early 1980s and low recruitment from 1989, with one strong year class in 1991.

Estimates and ranges of mid-spawning season virgin biomass (B_0), mid-spawning season mature biomass for 2000–01 (B_{mid01}), and 2001–02 (B_{mid02}) were obtained using MIAEL estimation (Table 10). 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. MIAEL estimate of B_0 for the base case was about 18 902 t; and estimates for sensitivity tests ranged from about 13 500 to 20 300 t.

Estimates of B_0 for all sensitivities were either similar to or lower than the base case, except for Sensitivity 1 (low *M*, where *M* was 0.2 y^{-1}), and Sensitivity 8 (reduce ages). Estimates of B_{mid02} were lower than B_{mid01} in all cases, suggesting that stock size will continue to decline in the next year. The model assumes average recruitment after 1995, an assumption that cannot be verified with current data. However, Sensitivity 6 (where year class strengths for both 1996 and 1997 were estimated to be low) results in an even lower B_{mid02} estimate (about 8% of B_0). Sensitivity 7 indicated that the model was not sensitive to the penalty imposed to encourage year class strengths to average one. Sensitivity 5, estimating the ogives for home and spawning selectivity for ages 2 to 12+, gave lower estimates of mid-spawning season virgin biomass (B_0), mid-spawning season mature biomass for 2000–01 (B_{mid01}), and 2001–02 (B_{mid02}), than for the base case.

The biomass trajectories of minimum and maximum biomass and the MIAEL estimates of B_{mid01} and B_{mid02} as a percentage of B_0 for each of the base case and sensitivity analyses are shown as Figures A1–A6 and A8–A10 (Appendix A). Least squares trajectories are similar for most runs, suggesting that biomass increased during the late 1980s (a result of strong recruitment) followed by a decline caused by low recruitment and increased catches.

Table 9: Estimated year class strengths[1], mean year class strength (Mean YCS), and estimated recruitment standard deviation (Rsd) for the base cases and the sensitivity analyses.

Year	Base	Sensitivity 1	2	3	4	5	6	7	8
		Low *M*	High *M*	Increase MinMax	Reduce r_{max}	Estimate ogives	Extra YCS	No YCS penalty	Reduce ages
1978	0.66	0.54	0.78	0.66	0.66	0.53	0.73	0.88	1.24
1979	0.09	0.08	0.09	0.09	0.09	0.07	0.09	0.08	0.07
1980	2.42	2.17	2.68	2.42	2.42	2.14	2.68	3.20	2.29
1981	0.26	0.26	0.26	0.26	0.26	0.30	0.27	0.28	0.28
1982	4.30	4.09	4.40	4.30	4.30	4.04	4.61	5.30	4.13
1983	0.81	0.82	0.80	0.81	0.81	0.95	0.88	0.93	0.69
1984	3.22	3.24	3.22	3.22	3.22	3.59	3.38	3.80	2.76
1985	0.88	0.92	0.85	0.88	0.88	0.92	0.93	1.02	0.79
1986	1.64	1.73	1.56	1.64	1.64	1.62	1.73	1.91	1.62
1987	0.86	0.93	0.80	0.86	0.86	0.88	0.90	1.00	0.65
1988	0.99	1.09	0.91	0.99	0.99	1.03	1.04	1.15	1.02
1989	0.59	0.66	0.53	0.59	0.59	0.62	0.61	0.68	0.41
1990	0.22	0.25	0.19	0.22	0.22	0.24	0.22	0.25	0.20
1991	1.52	1.73	1.34	1.52	1.52	1.66	1.69	1.77	1.33
1992	0.17	0.19	0.15	0.17	0.17	0.17	0.17	0.20	0.16
1993	0.13	0.15	0.11	0.13	0.13	0.14	0.13	0.15	0.12
1994	0.20	0.24	0.17	0.20	0.20	0.24	0.22	0.25	0.20
1995	0.21	0.26	0.17	0.21	0.21	0.30	0.25	0.26	0.26
1996[2]	–	–	–	–	–	–	0.12	–	–
1997[2]	–	–	–	–	–	–	0.01	–	–
Mean YCS	1.06	1.08	1.06	1.06	1.06	1.08	1.03	1.28	1.01
Rsd	1.16	1.12	1.20	1.16	1.16	1.14	1.48	1.19	1.17

1. Year class strengths not estimated, '–', were assumed to be 1.
2. The 1996 and 1997 year class strengths were only estimated for Sensitivity 6 (YCS).

Model residuals for the base case fits to SKI 1 and 2 proportion-at-age and CPUE indices are shown in Figure 5. Residual analyses suggested evidence of undesirable structure within the model fits. In particular, residual analysis for the catch-at-age data for SKI 1 and the CPUE indices for SKI 2 suggested that fits to these time series could be improved. Sensitivity tests (Sensitivity 5 and other exploratory analyses not reported here) where parameters for estimating year class strengths, fishing selectivity ogives, or maturity ogives were freed within the estimation model did not appear to resolve these problems (see Figure A7, Appendix A).

The exclusion of low and high ages from the SKI 1 catch-at-age data showed a substantial improvement in the residual plots (Figure A11, Appendix A), although there was little change in the model fits to the SKI 2 catch-at-age data or the CPUE indices. Estimates of biomass were similar to that for the base case, with B_0 slightly higher and B_{mid01} slightly lower.

Table 10: First step least squares (LSQ), bounds, second step least squares, MIAEL estimates of biomass, and percent performance indices (Perf. index for the base cases and sensitivity analyses. Estimates are presented either in tonnes (B_0) or as $\%B_0$ (B_{mid01} and B_{mid02}).

Parameter	Sensitivity	1st step LSQ	Bounds (B_{min}–B_{max})	2nd step LSQ	MIAEL	Perf. index
B_0	Base	12 495	11 413–64 088	11 980	18 902	36.6
	Sensitivity 1 (Low *M*)	13 163	12 637–66 100	12 885	20 342	36.6
	Sensitivity 2 (High *M*)	12 988	10 288–64 388	12 042	17 914	38 8
	Sensitivity 3 (Increase MinMax)	12 495	10 875–25 563	11 981	13 508	56.1
	Sensitivity 4 (Reduce r_{max})	12 495	11 423–64 338	11 980	18 943	36.5
	Sensitivity 5 (Estimate ogives)	10 810	9 708–57 108	10 515	16 260	39.5
	Sensitivity 6 (Extra YCS)	11 612	10 324–60 702	11 504	17 395	39.1
	Sensitivity 7 (No YCS penalty)	10 800	9 269–54 862	10 238	15 634	38.8
	Sensitivity 8 (Reduce ages)	13 712	11 719–70 442	13 143	19 814	40.0
B_{mid01}	Base	16.6%	9.6–70.7%	13.5%	15.5%	73.9
	Sensitivity 1 (Low *M*)	13.0%	8.9–81.2%	10.9%	13.2%	76.6
	Sensitivity 2 (High *M*)	20.3%	6.4–59.8%	16.2%	16.2%	77.8
	Sensitivity 3 (Increase MinMax)	16.6%	5.5–51.8%	13.5%	13.5%	77.3
	Sensitivity 4 (Reduce r_{max})	16.6%	9.7–70.7%	13.5%	15.5%	74.1
	Sensitivity 5 (Estimate ogives)	15.0%	5.8–75.6%	12.8%	13.3%	83.5
	Sensitivity 6 (Extra YCS)	15.9%	5.5–75.0%	15.1%	15.2%	81.6
	Sensitivity 7 (No YCS penalty)	20.6%	6.3–83.1%	16.0%	16.2%	81.1
	Sensitivity 8 (Reduce ages)	16.1%	4.9–64.9%	13.3%	13.4%	81.7
B_{mid02}	Base	–	6.5–61.8%	10.1%	11.5%	74.4
	Sensitivity 1 (Low *M*)	–	5.8–72.8%	7.6%	9.0%	82.1
	Sensitivity 2 (High *M*)	–	4.7–51.5%	12.8%	12.7%	77.7
	Sensitivity 3 (Increase MinMax)	–	3.8–44.7%	10.1%	10.1%	75.2
	Sensitivity 4 (Reduce r_{max})	–	7.1–61.9%	10.1%	11.7%	74.0
	Sensitivity 5 (Estimate ogives)	–	3.8–65.6%	8.8%	9.2%	83.4
	Sensitivity 6 (Extra YCS)	–	1.8–63.7%	6.6%	8.1%	79.8
	Sensitivity 7 (No YCS penalty)	–	4.2–72.4%	11.6%	11.8%	81.3
	Sensitivity 8 (Reduce ages)	–	3.7–56.9%	4.7%	5.7%	82.0

1. '–' indicates that the value was not calculated.

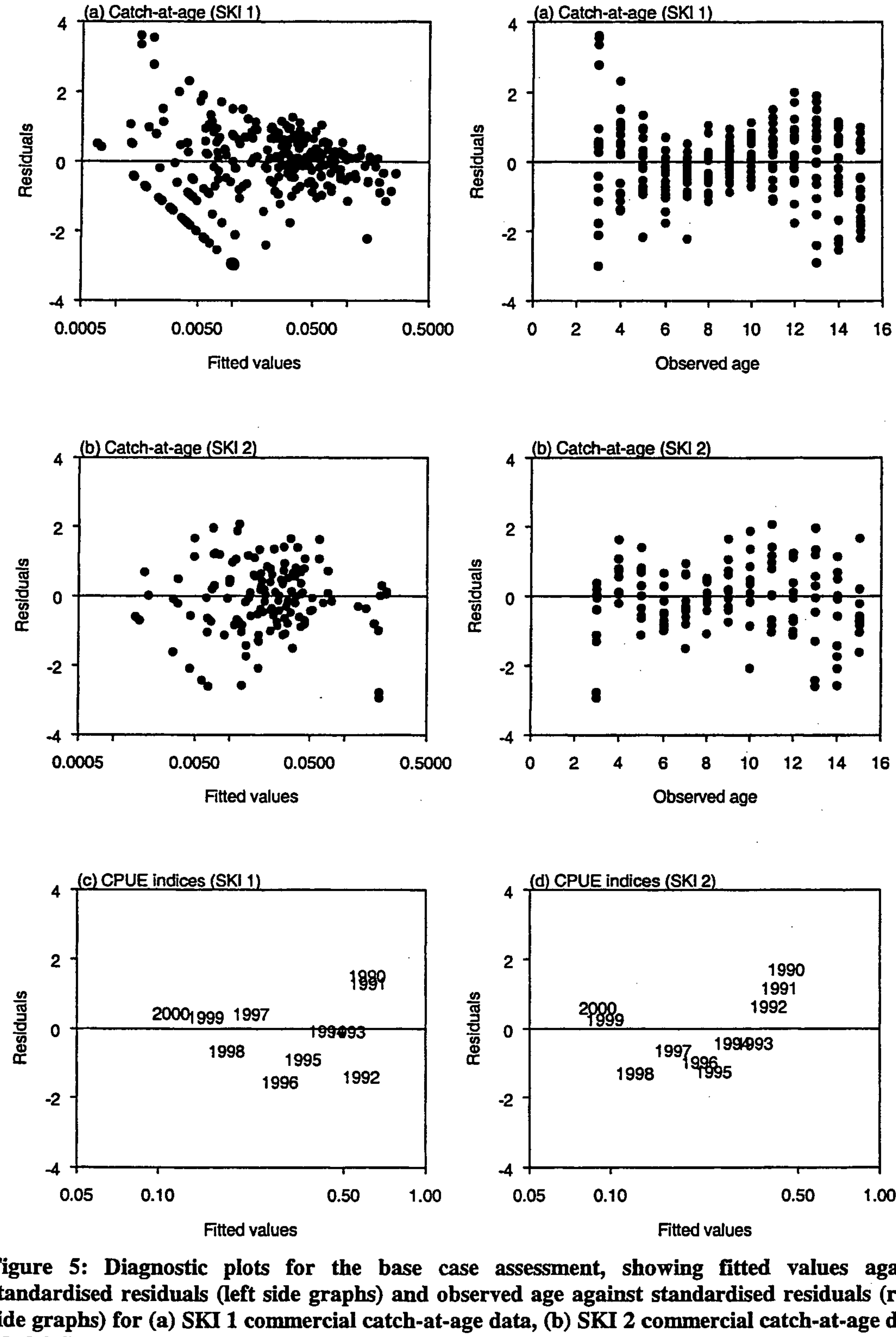

Figure 5: Diagnostic plots for the base case assessment, showing fitted values against standardised residuals (left side graphs) and observed age against standardised residuals (right side graphs) for (a) SKI 1 commercial catch-at-age data, (b) SKI 2 commercial catch-at-age data. Model fits to CPUE data are shown as (c) SKI 1 CPUE indices (with points marked by index year) and (d) SKI 2 CPUE indices (with points marked by index year).

5. YIELD ESTIMATES

5.1 Estimation of Maximum Constant Yield (MCY)

The method used to estimate MCY was MCY = ρB_0, where ρ is determined for each stock using the simulation method described by Francis (1992), and is such that the projected biomass falls below 20% B_0 exactly 10% of the time. B_0 is estimated by the MIAEL method of Cordue (1998b, 1998c), with associated performance indices indicating how well B_0 is estimated within the given range of values. Estimates of MCY are given in Table 11, assuming a catch ratio between the spawning and non-spawning grounds equal to the current TAC, i.e., of 460:520.

Francis (1992) also suggested that where current spawning biomass was below 20% B_0, the MCY should be scaled down linearly according to current stock status. This assessment provides strong evidence that the current biomass of northern gemfish is below 20% B_0, and therefore the MIAEL point estimate for B_{mid01} of 15.5% suggests a rescaled MCY of 1010 t (Table 11).

Table 11: Estimates of B_{MCY} (as % B_0), MCY (as %B_0) and MCY (t), rescaled MCY, B_0 and associated performance indices (Perf. index) for SKI 1 & 2. The rescaled MCY gives MCY where B_{mid01} is less than 20% B_0, as per Francis (1992).

Sensitivity	B_{MCY} (%B_0)	MCY (%B_0)	MCY range	MCY	Rescaled MCY	B_0 (MIAEL)	Perf. index
Base	58.3	6.9	787–4 422	1 304	1 010	18 902	36.6
Sensitivity 1 (Low *M*)	55.7	5.7	720–3 768	1 159	768	20 342	36.6
Sensitivity 2 (High *M*)	60.5	8.2	844–5 276	1 469	1 187	17 914	38.8
Sensitivity 3 (Increase MinMax)	58.3	6.9	750–1 764	932	631	13 508	56.1
Sensitivity 4 (Reduce r_{max})	58.3	6.9	788–4 439	1 307	1 013	18 934	36.5
Sensitivity 5 (Estimate ogives)	57.3	7.4	752–4 525	1 199	796	17 321	39.5
Sensitivity 6 (Extra YCS)	58.3	6.9	712–4 188	1 200	910	17 395	39.1
Sensitivity 7 (No YCS penalty)	58.3	6.9	640–3 785	1 079	876	15 634	38.8
Sensitivity 8 (Reduce ages)	58.3	6.9	809–4 860	1 367	915	19 814	40.0

5.2 Estimation of Current Annual Yield (CAY)

The simulation method of Francis (1992) was also used to determine CAY. CAY is estimated by the MIAEL method of Cordue (1998b, 1998c), with associated performance indices indicating how well CAY is estimated within the given range of values. The catch ratio assumed for future catches was assumed to be the current TACCs for SKI 1 and SKI 2 respectively, i.e., a catch ratio of 460:520 for the spawning and home grounds respectively. The estimates of B_{MAY}, MAY, and the least squares and MIAEL estimates of CAY are given in Table 12.

Table 12: Estimates of B_{MAY} (as % B_0), MAY (as %B_0) , least squares estimates of CAY (t), MIAEL estimates of CAY, and associated performance indices (Perf. index) for SKI 1 & 2.

Sensitivity	B_{MAY} (%B_0)	MAY (%B_0)	CAY range	CAY (LSQ)	CAY (MIAEL)	Perf. index
Base	36.8	10.3	380–8 881	485	914	45.2
Sensitivity 1 (Low *M*)	34.7	8.2	310–9 293	360	760	47.9
Sensitivity 2 (High *M*)	37.3	12.5	380–8 834	684	995	46.7
Sensitivity 3 (Increase MinMax)	36.4	10.2	277–2 738	485	555	66.7
Sensitivity 4 (Reduce r_{max})	36.4	10.2	382–8 921	485	919	45.3
Sensitivity 5 (Estimate ogives)	35.3	11.1	260–8 552	423	706	48.2
Sensitivity 6 (Extra YCS)	36.4	10.2	132–7 964	345	452	52.4
Sensitivity 7 (No YCS penalty)	36.4	10.2	255–8 796	467	715	49.8
Sensitivity 8 (Reduce ages)	36.4	10.2	295–9 085	341	712	50.1

5.3 Estimation of biomass projections

Five-year projections using catch levels at the current TACC (for the home and spawning seasons of 520 and 460 t respectively) were made for the base case assessment, assuming that recruitment varies with parameter rsd = 1.0 (see Table 7) for all year class strengths after 1995 (see Table 9). The results are given in Table 13, and indicate that stock risk is moderate but poorly defined. The probability that projected catch levels will move biomass towards B_{MSY} (defined as B_{MCY}) is about 0.6. However, given catches at the current TACC, it is likely that biomass in 2005 will have changed little from the 2001 level.

Table 13: Bounds, least squares (LSQ), and MIAEL estimates with performance indices (Perf. index) of the following stock risk definitions: *Stock risk = P(B_{mid} falls below 20% B_0 in the current year or the next 5 years)*; P_k = P($B_{mid2005}$ moves in the direction of B_{MSY} from $B_{mid2000}$); $B_{mid2005}/B_{mid2000}$ = E[$B_{mid2005}/B_{mid2000}$]; and Projected $B_{mid2005}$ = E[$B_{mid2005}/B_0$].

Estimate	Range	LSQ	MIAEL	Perf. index
Stock risk	0.00–1.00	0.08	0.28	0.39
P_k	0.52–0.67	0.59	0.59	0.09
$B_{mid2005}/B_{mid2000}$	0.98–1.97	1.10	–	–
Projected $B_{mid2005}$	0.20–0.69	0.45	–	–

1. '–' indicates that the value was not calculated.

6. MANAGEMENT IMPLICATIONS

There are more data on which to determine stock relationships for northern gemfish than were available for the 1997 and 1998 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 (Horn & Hurst 1999, Hurst & Bagley 1998). 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 recent years. Therefore, only one stock hypothesis, SKI 1 & 2, was modelled in the 2001 assessment.

Standardised CPUE indices have suggested strong declines in the SKI 1E and SKI 2 fisheries during the 1990s, with a flattening off or slight recovery in the last few years. Year classes since 1988 appear to have been relatively weak, except for one strong cohort in 1991. Model results suggest the stock is most likely to be below the level that would support the MSY, and also suggest that mid-spawning season biomass in 2000–01 is likely to decline in 2001–02 — if catch levels at the level of the 1999–2000 TACs are taken and assumptions about recruitment variability and average recruitment since 1995 are valid. The relative strengths of year classes since 1995 are unknown, and projections as to stock status in 2002 relative to 2001 are likely to be very sensitive to assumptions of their relative size. Sensitivity analyses where the 1996 and 1997 year classes were estimated suggested an even greater decline in 2001–2002 stock status than for the base assessment.

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Appendix A: Supplementary tables and figures for the stock assessment

Table A1: Assumed maturity, home ground selectivity, and spawning ground selectivity ogives for the base case model (Hurst et al. 2000).

Age	Maturity		Home ground		Spawning ground	
	Male	Female	Male	Female	Male	Female
1	0.00	0.00	0.01	0.01	0.00	0.00
2	0.00	0.00	0.05	0.05	0.00	0.00
3	0.00	0.00	0.50	0.50	1.00	1.00
4	0.01	0.01	0.95	0.95	1.00	1.00
5	0.02	0.01	1.00	1.00	1.00	1.00
6	0.20	0.02	1.00	1.00	1.00	1.00
7	0.40	0.20	1.00	1.00	1.00	1.00
8	0.80	0.40	1.00	1.00	1.00	1.00
9	1.00	0.80	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00
11	1.00	1.00	1.00	1.00	1.00	1.00
12+	1.00	1.00	1.00	1.00	1.00	1.00

Table A2: Estimated maturity ogive and home ground selectivity ogive for Sensitivity 5 (Estimated ogives).

Age	Maturity		Home ground	
	Male	Female	Male	Female
1	–	–	0.00	0.00
2	0.01	0.01	0.09	0.00
3	0.02	0.01	0.41	0.30
4	0.15	0.02	0.81	0.68
5	0.38	0.10	1.14	0.94
6	0.59	0.20	1.32	1.03
7	0.97	0.29	1.36	0.99
8	0.93	0.39	1.30	0.92
9	0.90	0.01	1.19	0.89
10	0.90	0.99	1.08	0.92
11	0.90	0.89	1.01	0.98
12+	1.00	1.00	1.00	1.02

Table A3: Estimated catchability coefficients (*q*) of the CPUE indices for the base case and sensitivity analyses.

Sensitivity	SKI 1 CPUE	SKI 2 CPUE
Base	0.000054	0.000022
Sensitivity 1 (Low *M*)	0.000065	0.000027
Sensitivity 2 (High *M*)	0.000042	0.000017
Sensitivity 3 (Increase MinMax)	0.000054	0.000022
Sensitivity 4 (Reduce r_{max})	0.000054	0.000022
Sensitivity 5 (Estimate ogives)	0.000096	0.000028
Sensitivity 6 (Extra YCS)	0.000057	0.000024
Sensitivity 7 (No YCS penalty)	0.000052	0.000022
Sensitivity 8 (Reduce ages)	0.000050	0.000021

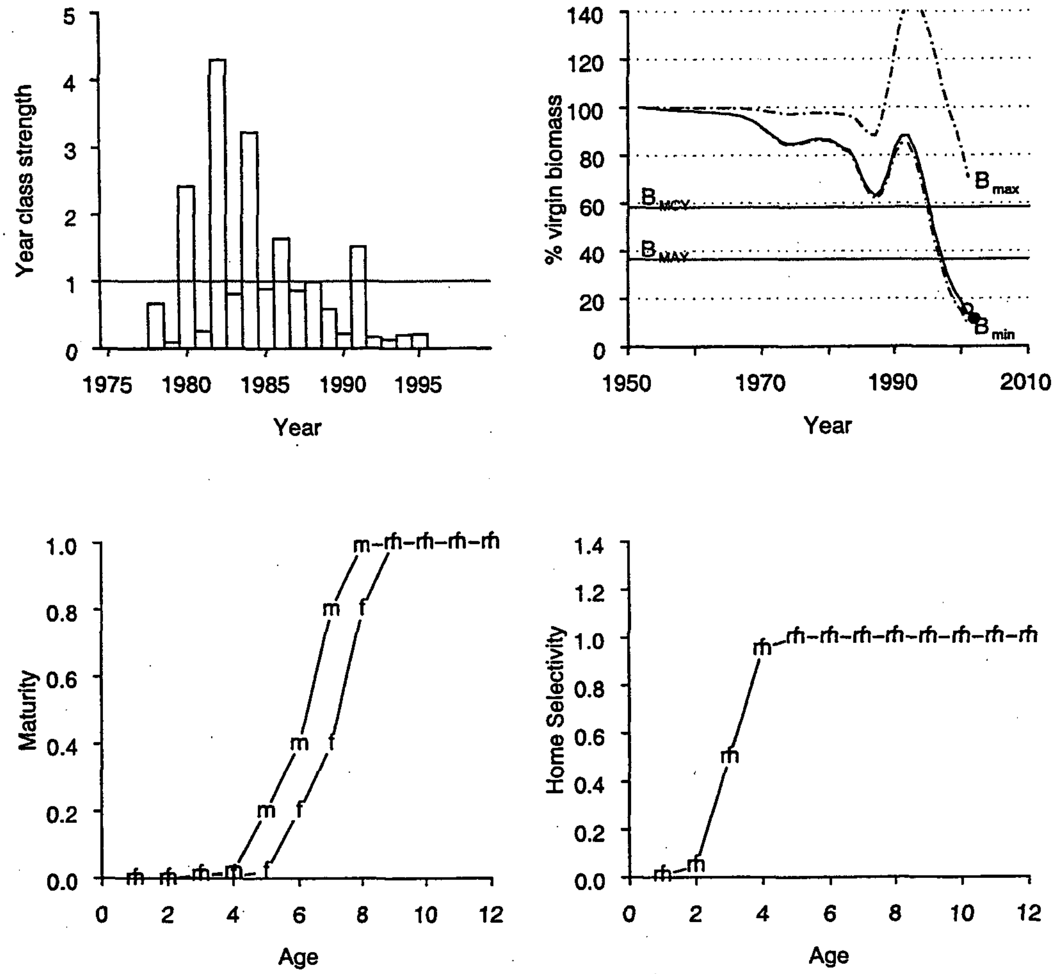

Figure A1: Base case estimated year class strengths for gemfish (top left). Estimated biomass trajectory for gemfish (top right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively. Bottom left and bottom right show the shape of the assumed male and female maturity and home selectivity ogives respectively.

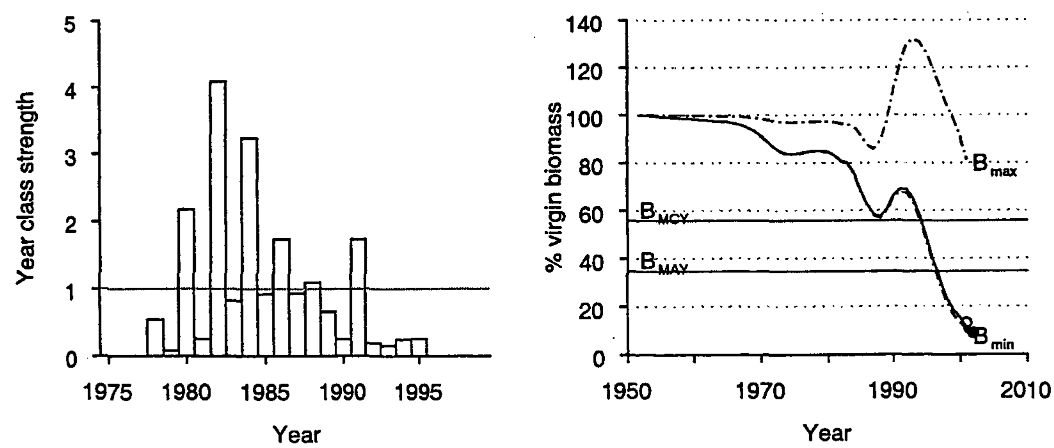

Figure A2: Sensitivity 1 (Low *M*) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

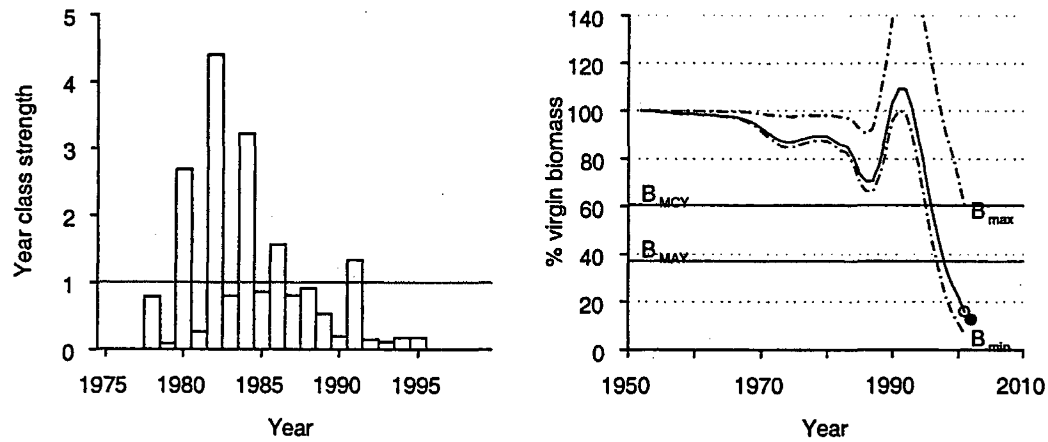

Figure A3: Sensitivity 2 (High *M*) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

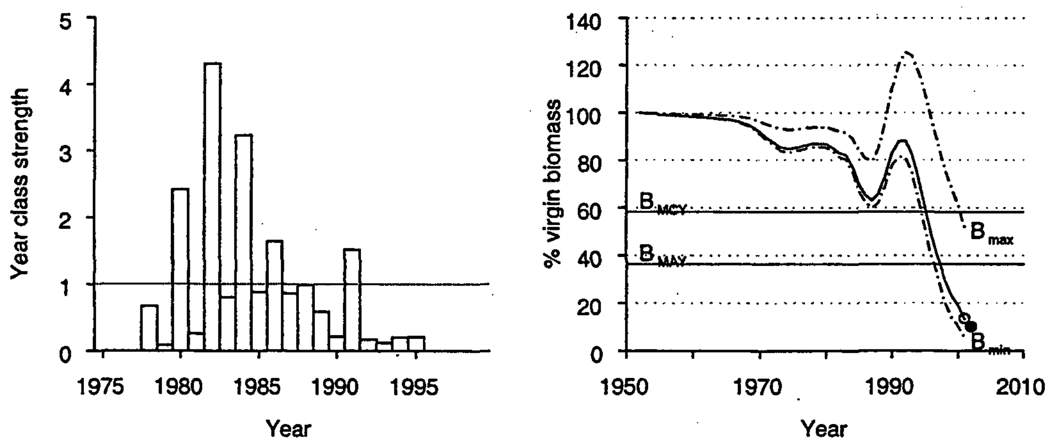

Figure A4: Sensitivity 3 (Increase MinMax) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

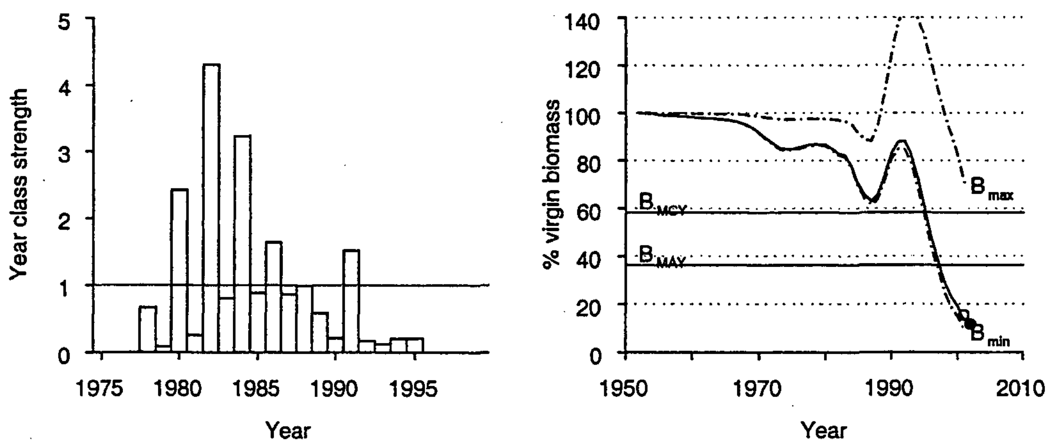

Figure A5: Sensitivity 4 (Reduce r_{max}) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

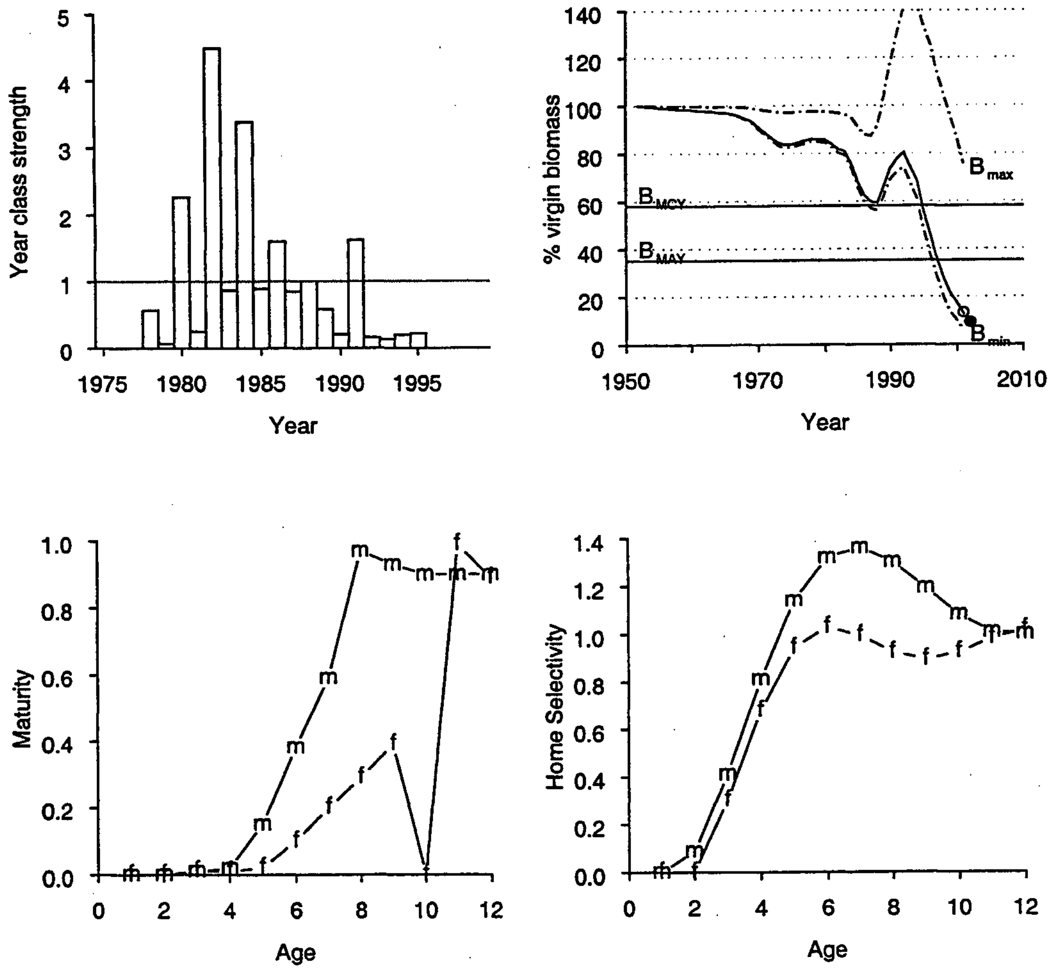

Figure A6: Sensitivity 5 (Estimate ogives) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively. Bottom left and bottom right show the shape of the estimated male and female maturity and home selectivity ogives respectively.

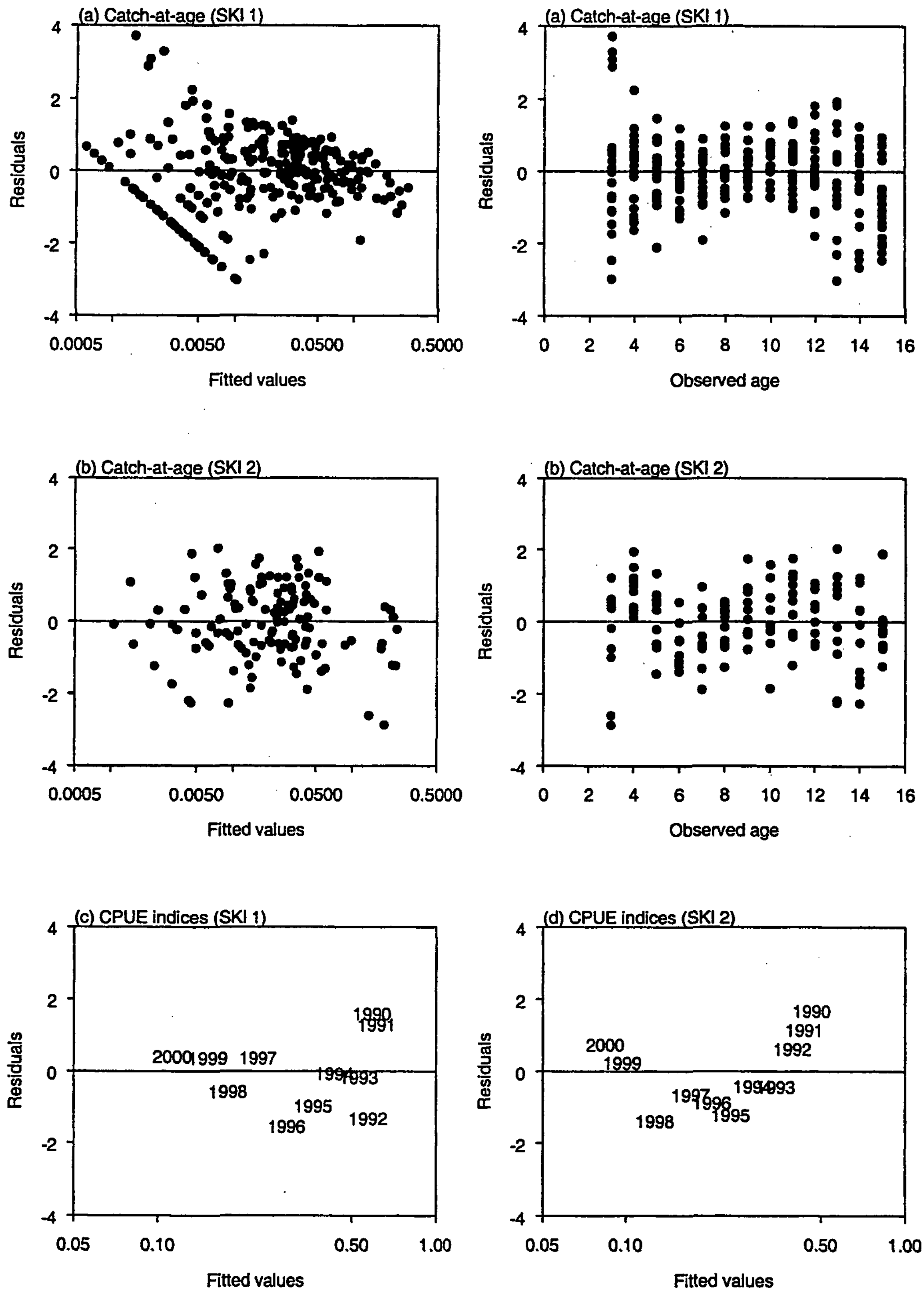

Figure A7: Diagnostic plots for the Sensitivity 5 (Estimate ogives) assessment, showing fitted values against standardised residuals (left side graphs) and observed age against standardised residuals (right side graphs) for (a) SKI 1 commercial catch-at-age data, (b) SKI 2 commercial catch-at-age data. Model fits to CPUE data are shown as (c) SKI 1 CPUE indices (with points marked by index year) and (d) SKI 2 CPUE indices (with points marked by index year).

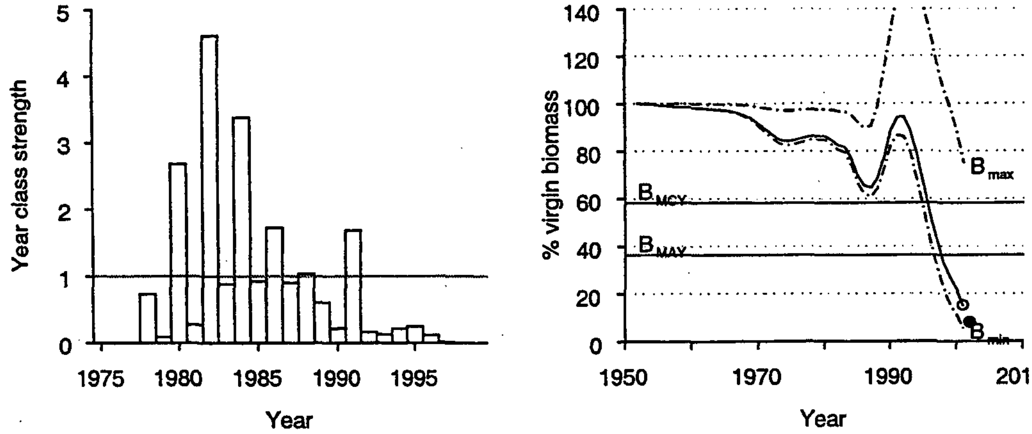

Figure A8: Sensitivity 6 (Extra YCS) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

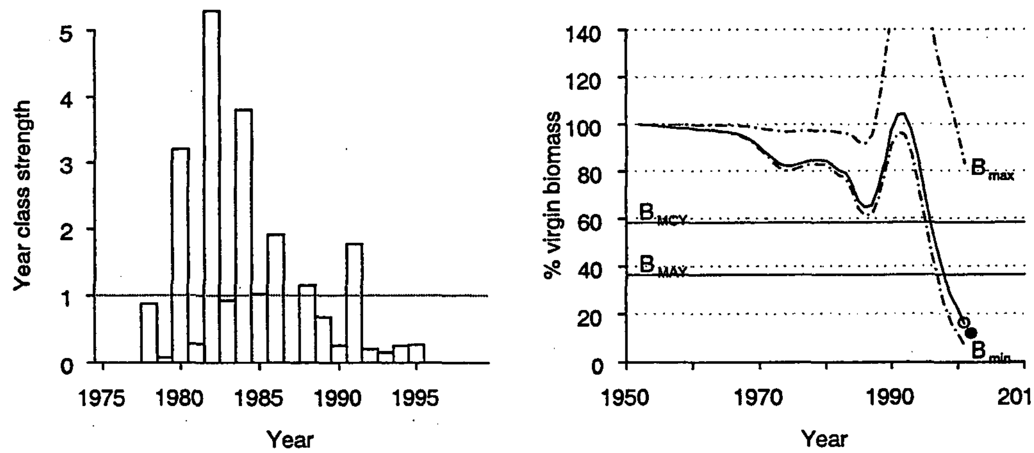

Figure A9: Sensitivity 7 (No YCS penalty) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

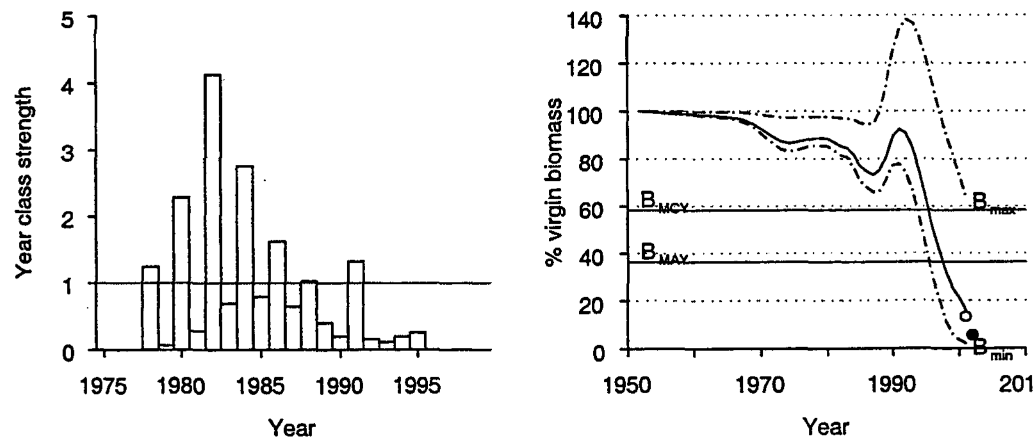

Figure A10: Sensitivity 8 (Reduce ages) estimated year class strengths for gemfish (left). Estimated biomass trajectory for gemfish (right), with B_{min} and B_{max} bounds (dashed lines). The positions of the MIAEL estimates of current biomass (B_{mid01}) and projected biomass (B_{mid02}) are shown as open and filled circles respectively.

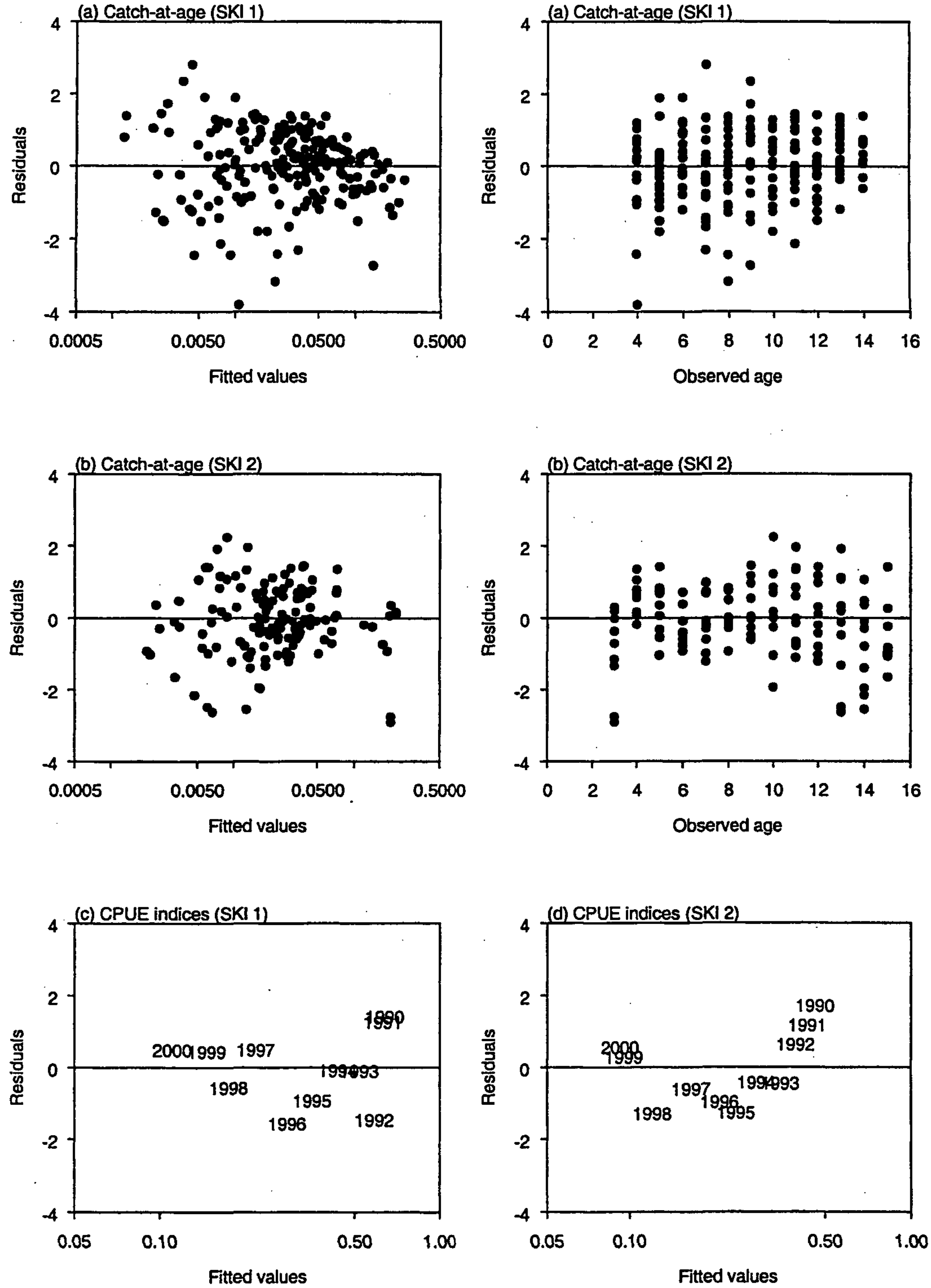

Figure A11: Diagnostic plots for the Sensitivity 8 (Reduce ages) assessment, showing fitted values against standardised residuals (left side graphs) and observed age against standardised residuals (right side graphs) for (a) SKI 1 commercial catch-at-age data, (b) SKI 2 commercial catch-at-age data. Model fits to CPUE data are shown as (c) SKI 1 CPUE indices (with points marked by index year) and (d) SKI 2 CPUE indices (with points marked by index year).

Appendix B: Length and age catch sampling for SKI 1 & 2, and SKI 3 & 7

Table B1: Numbers of measured and aged fish by year for males and females, and the number of samples and estimated mean weighted c.v. by age for SKI 1E.

Year	Males measured	Females measured	Aged	Samples	Mean c.v.
1989	1 333	1 157	311	9	0.19
1990	545	578	375	7	0.23
1991	696	569	295	8	0.26
1992	1 045	862	340	9	0.20
1993	1 215	1 115	337	10	0.22
1994	1 073	734	321	8	0.26
1997	2 601	2 077	419	15	0.20
1998	896	683	433	7	0.25
1999	600	411	251	5	0.31

Table B2: Numbers of measured and aged fish by year for males and females, and the number of samples and estimated mean weighted c.v. by age for SKI 1W.

Year	Males measured	Females measured	Aged	Samples	Mean c.v.
1996	780	497	373	5	0.27
1997	2 136	1 683	404	14	0.21
1998	1 881	1 466	435	13	0.23
1999	1 173	989	461	11	0.21

Table B3: Numbers of measured and aged fish by year for males and females, and the number of samples and estimated mean weighted c.v. by age for SKI 2.

Year	Males measured	Females measured	Aged	Samples	Mean c.v.
1996	1 965	2 338	698	21	0.13
1997	1 149	1 657	399	11	0.20
1998	867	1 370	415	11	0.21
1999	1 119	1 403	436	21	0.21
2000	275	447	506	15	0.26

Table B4: Proportions at age (*p*) and coefficients of variation (c.v.) for gemfish from commercial catches in SKI 1E, for the years 1989–1994, 1997–1999.

Sex	Age	1989		1990		1991		1992		1993		1994		1997		1998		1999	
		p	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.
Male	2	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.73	0.000	0.00	0.000	0.00	0.002	1.28	0.000	0.00	0.000	0.00
	3	0.010	0.54	0.072	0.32	0.000	0.00	0.041	0.26	0.001	1.30	0.018	0.44	0.001	1.22	0.001	3.15	0.005	1.27
	4	0.034	0.23	0.070	0.29	0.021	0.47	0.017	0.34	0.014	0.32	0.000	0.00	0.034	0.22	0.005	0.87	0.012	0.78
	5	0.199	0.13	0.150	0.20	0.104	0.22	0.054	0.25	0.039	0.26	0.051	0.19	0.042	0.22	0.025	0.37	0.050	0.39
	6	0.115	0.22	0.214	0.15	0.045	0.43	0.138	0.19	0.099	0.23	0.120	0.22	0.361	0.09	0.107	0.23	0.030	0.29
	7	0.379	0.10	0.127	0.20	0.221	0.18	0.191	0.16	0.162	0.25	0.154	0.21	0.069	0.31	0.257	0.13	0.056	0.23
	8	0.069	0.27	0.208	0.16	0.109	0.27	0.326	0.12	0.268	0.17	0.178	0.21	0.087	0.27	0.099	0.23	0.279	0.15
	9	0.129	0.19	0.049	0.33	0.331	0.14	0.074	0.28	0.257	0.17	0.044	0.48	0.152	0.18	0.074	0.28	0.099	0.52
	10	0.008	0.65	0.066	0.28	0.052	0.40	0.120	0.21	0.072	0.29	0.220	0.19	0.081	0.27	0.113	0.21	0.108	0.54
	11	0.010	0.66	0.007	1.04	0.062	0.35	0.018	0.50	0.079	0.28	0.060	0.36	0.078	0.24	0.040	0.38	0.177	0.33
	12	0.041	0.29	0.012	0.68	0.005	1.01	0.019	0.44	0.004	0.72	0.103	0.27	0.011	0.58	0.082	0.24	0.028	0.53
	13	0.000	0.00	0.025	0.53	0.039	0.41	0.000	0.00	0.006	0.71	0.022	0.62	0.057	0.23	0.054	0.30	0.077	0.25
	14	0.000	0.00	0.000	0.00	0.000	0.00	0.001	1.41	0.000	0.00	0.026	0.50	0.005	0.71	0.077	0.25	0.024	0.45
	15	0.005	0.87	0.000	0.00	0.006	1.10	0.000	0.00	0.000	0.00	0.003	1.39	0.012	0.44	0.029	0.46	0.036	0.34
	16	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.008	0.58	0.015	0.64	0.008	0.64
	17	0.000	0.00	0.000	0.00	0.005	1.05	0.000	0.00	0.000	0.00	0.001	0.71	0.002	1.02	0.008	0.70	0.011	0.99
	18	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.012	0.64	0.004	0.00
Female	2	0.000	0.00	0.007	0.75	0.000	0.00	0.023	0.31	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
	3	0.003	2.17	0.032	0.35	0.000	0.00	0.058	0.19	0.000	0.00	0.025	0.45	0.002	1.08	0.000	4.31	0.000	1.54
	4	0.004	0.70	0.013	0.53	0.011	0.62	0.053	0.19	0.002	0.50	0.004	0.84	0.021	0.25	0.003	1.32	0.007	5.31
	5	0.070	0.26	0.023	0.42	0.023	0.45	0.038	0.29	0.012	0.46	0.003	1.20	0.014	0.36	0.005	1.48	0.002	0.56
	6	0.051	0.34	0.159	0.20	0.027	0.42	0.047	0.31	0.057	0.27	0.022	0.40	0.224	0.11	0.026	0.44	0.017	1.38
	7	0.334	0.12	0.114	0.24	0.183	0.21	0.101	0.22	0.137	0.18	0.110	0.26	0.054	0.31	0.110	0.21	0.035	0.46
	8	0.101	0.23	0.357	0.13	0.128	0.27	0.198	0.16	0.140	0.23	0.112	0.28	0.059	0.28	0.082	0.25	0.209	0.20
	9	0.227	0.17	0.083	0.28	0.273	0.18	0.157	0.16	0.295	0.15	0.067	0.40	0.103	0.22	0.096	0.23	0.066	0.37
	10	0.013	0.60	0.114	0.25	0.081	0.33	0.157	0.18	0.070	0.33	0.277	0.17	0.088	0.23	0.212	0.15	0.131	0.29
	11	0.082	0.26	0.003	1.08	0.166	0.23	0.037	0.35	0.184	0.18	0.114	0.25	0.127	0.18	0.082	0.29	0.220	0.23
	12	0.073	0.30	0.054	0.38	0.035	0.48	0.098	0.21	0.021	0.46	0.188	0.19	0.056	0.29	0.139	0.21	0.027	0.37
	13	0.021	0.42	0.012	0.73	0.051	0.36	0.017	0.52	0.072	0.28	0.006	0.88	0.182	0.13	0.054	0.37	0.085	0.23
	14	0.016	0.54	0.029	0.42	0.006	0.92	0.013	0.64	0.008	0.61	0.050	0.35	0.015	0.44	0.123	0.23	0.037	0.36
	15	0.000	0.00	0.000	0.00	0.005	0.84	0.003	1.08	0.002	1.08	0.003	1.18	0.049	0.30	0.019	0.55	0.111	0.25
	16	0.006	0.55	0.000	0.00	0.000	0.00	0.000	0.00	0.003	0.89	0.019	0.67	0.003	1.03	0.036	0.35	0.030	0.67
	17	0.000	0.00	0.000	0.00	0.006	1.31	0.000	0.00	0.000	0.00	0.001	1.89	0.000	0.00	0.009	0.70	0.024	0.69
	18	0.000	0.00	0.000	0.00	0.006	0.93	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.004	0.41	0.000	0.00
	19	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.004	0.98	0.000	0.00	0.000	0.59

Table B5: Proportions at age (*p*) and coefficients of variation (c.v.) for gemfish from commercial catches in SKI 1W, for the years 1996–1999.

Sex	Age	1996		1997		1998		1999	
		p	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.
Male	2	0.000	0.00	0.000	0.00	0.000	0.00	0.000	5.26
	3	0.002	1.03	0.000	0.00	0.000	2.40	0.003	0.80
	4	0.025	0.31	0.002	1.23	0.004	0.74	0.015	0.32
	5	0.184	0.16	0.017	0.35	0.010	0.36	0.044	0.24
	6	0.038	0.41	0.220	0.10	0.061	0.27	0.058	0.37
	7	0.062	0.36	0.055	0.31	0.195	0.15	0.138	0.27
	8	0.109	0.28	0.052	0.31	0.059	0.32	0.282	0.12
	9	0.120	0.26	0.168	0.18	0.066	0.29	0.023	0.21
	10	0.156	0.21	0.138	0.20	0.136	0.19	0.054	0.21
	11	0.063	0.34	0.158	0.17	0.080	0.26	0.114	0.16
	12	0.174	0.20	0.039	0.41	0.112	0.21	0.032	0.41
	13	0.014	0.64	0.105	0.18	0.059	0.29	0.093	0.24
	14	0.039	0.38	0.015	0.59	0.118	0.19	0.051	0.45
	15	0.000	0.00	0.029	0.46	0.021	0.36	0.067	0.31
	16	0.004	1.00	0.000	0.00	0.064	0.28	0.018	0.76
	17	0.004	1.06	0.000	0.00	0.016	0.50	0.008	0.54
	18	0.005	1.02	0.002	0.58	0.001	1.01	0.000	1.00
Female	2	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
	3	0.003	1.11	0.001	1.32	0.000	0.00	0.003	0.00
	4	0.011	0.77	0.001	1.56	0.000	0.00	0.001	0.53
	5	0.079	0.23	0.006	0.63	0.004	0.43	0.008	1.22
	6	0.056	0.33	0.203	0.11	0.012	0.44	0.006	0.32
	7	0.103	0.25	0.043	0.35	0.053	0.26	0.034	0.28
	8	0.145	0.20	0.072	0.27	0.055	0.32	0.173	0.13
	9	0.103	0.24	0.149	0.18	0.073	0.26	0.062	0.27
	10	0.097	0.26	0.084	0.26	0.208	0.14	0.117	0.19
	11	0.092	0.26	0.121	0.21	0.064	0.28	0.178	0.14
	12	0.158	0.21	0.052	0.30	0.157	0.18	0.049	0.43
	13	0.036	0.43	0.189	0.16	0.063	0.27	0.144	0.22
	14	0.074	0.31	0.029	0.39	0.170	0.15	0.058	0.34
	15	0.002	1.29	0.034	0.35	0.031	0.38	0.111	0.20
	16	0.021	0.50	0.009	0.76	0.086	0.23	0.017	0.40
	17	0.017	0.63	0.000	0.00	0.013	0.47	0.014	0.41
	18	0.004	1.20	0.007	0.47	0.009	0.55	0.000	0.00
	19	0.000	0.00	0.000	0.00	0.004	0.99	0.024	0.00

Table B6: Proportions at age (*p*) and coefficients of variation (c.v.) for gemfish from commercial catches in SKI 2, for the years 1996–2000. (Note that ages have been presented so as to make them comparable to the SKI age data by assigning the upcoming birthday.)

Sex	Age	1996		1997		1998		1999		2000	
		p	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.	*p*	c.v.
Male	2	0.000	0.00	0.002	0.64	0.000	0.00	0.001	11.84	0.000	0.00
	3	0.006	0.41	0.012	0.47	0.006	0.84	0.012	0.74	0.000	0.00
	4	0.019	0.26	0.049	0.22	0.101	0.27	0.101	0.24	0.071	0.33
	5	0.544	0.05	0.185	0.15	0.131	0.17	0.197	0.17	0.335	0.14
	6	0.042	0.22	0.474	0.08	0.161	0.17	0.035	0.37	0.176	0.23
	7	0.050	0.21	0.041	0.41	0.236	0.14	0.077	0.25	0.032	0.44
	8	0.057	0.20	0.028	0.48	0.056	0.32	0.274	0.13	0.064	0.40
	9	0.047	0.23	0.087	0.28	0.093	0.23	0.068	0.31	0.146	0.24
	10	0.058	0.20	0.040	0.48	0.118	0.20	0.059	0.32	0.024	0.54
	11	0.027	0.25	0.032	0.82	0.009	0.78	0.103	0.19	0.035	0.41
	12	0.064	0.19	0.016	0.71	0.051	0.24	0.020	0.45	0.055	0.35
	13	0.009	0.40	0.026	0.42	0.009	0.89	0.035	0.24	0.011	0.77
	14	0.058	0.20	0.000	0.00	0.017	0.30	0.004	0.96	0.023	0.55
	15	0.006	0.42	0.008	0.90	0.000	0.00	0.005	0.97	0.008	0.88
	16	0.006	0.41	0.000	0.00	0.014	0.43	0.000	0.00	0.009	0.93
	17	0.002	0.48	0.000	0.00	0.000	0.00	0.003	1.30	0.002	1.82
	18	0.005	0.84	0.000	0.00	0.000	0.00	0.005	1.01	0.004	2.98
Female	2	0.000	0.00	0.000	0.00	0.000	0.00	0.002	1.01	0.000	0.00
	3	0.004	0.43	0.011	0.31	0.011	0.48	0.006	0.80	0.000	0.00
	4	0.012	0.33	0.025	0.36	0.093	0.21	0.082	0.26	0.039	0.32
	5	0.429	0.05	0.169	0.15	0.056	0.22	0.193	0.12	0.310	0.13
	6	0.028	0.22	0.445	0.07	0.119	0.16	0.030	0.26	0.169	0.17
	7	0.048	0.19	0.041	0.33	0.165	0.15	0.093	0.16	0.038	0.34
	8	0.065	0.15	0.045	0.27	0.103	0.21	0.189	0.12	0.048	0.29
	9	0.024	0.24	0.080	0.19	0.081	0.24	0.049	0.28	0.111	0.21
	10	0.067	0.15	0.026	0.32	0.191	0.14	0.058	0.25	0.039	0.34
	11	0.028	0.23	0.065	0.22	0.031	0.34	0.104	0.19	0.071	0.26
	12	0.142	0.10	0.010	0.58	0.069	0.24	0.053	0.25	0.085	0.24
	13	0.032	0.21	0.048	0.28	0.023	0.39	0.058	0.23	0.027	0.45
	14	0.082	0.16	0.011	0.63	0.025	0.34	0.046	0.27	0.031	0.40
	15	0.003	0.64	0.018	0.43	0.020	0.31	0.008	0.58	0.008	1.15
	16	0.027	0.24	0.001	1.80	0.013	0.42	0.005	0.71	0.013	0.77
	17	0.000	0.00	0.005	0.79	0.000	0.00	0.016	0.37	0.005	0.95
	18	0.004	0.62	0.000	0.00	0.000	0.00	0.007	0.62	0.003	1.14
	19	0.003	0.70	0.000	0.00	0.000	0.00	0.002	1.02	0.002	2.06

Table B7: Proportions at age for males and females used in the stock assessment model. (Note: SKI 2 data have not been assigned a birthday in this table, and hence appear 1 year younger than in previous tables and plots; observed values of 0.000 were replaced by 0.001; the c.v. used in the models was estimated from a mean c.v. of 0.35, weighted by the number of samples for each year; age data for age 2 males and females in SKI 2 were used only for Sensitivity 6 (Extra YCS)).

Sex	Age	SKI 1E						SKI 1E & W				SKI 2				
		1989	1990	1991	1992	1993	1994	1996	1997	1998	1999	1996	1997	1998	1999	2000
Male	2											0.002	0.130	0.002	0.004	0.001
	3	0.005	0.033	0.001	0.022	0.001	0.012	0.001	0.001	0.001	0.002	0.008	0.021	0.043	0.039	0.027
	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	0.128
	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	0.067
	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	0.029	0.012
	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	0.025
	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	0.056
	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	0.009
	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	0.014
	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	0.021
	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	0.004
	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	0.009
	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	0.001	0.002	0.003
	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	0.001	0.003
Female	2											0.002	0.006	0.006	0.004	0.001
	3	0.001	0.018	0.001	0.027	0.001	0.009	0.001	0.001	0.001	0.001	0.007	0.014	0.054	0.050	0.024
	4	0.002	0.007	0.005	0.025	0.001	0.002	0.004	0.003	0.001	0.002	0.244	0.097	0.032	0.119	0.192
	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	0.105
	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	0.023
	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	0.030
	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	0.069
	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	0.036	0.024
	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	0.044
	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	0.053
	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	0.017
	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	0.019
	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	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	0.008
Mean c.v.		0.35	0.37	0.36	0.35	0.34	0.36	0.41	0.28	0.30	0.31	0.32	0.38	0.38	0.32	0.35

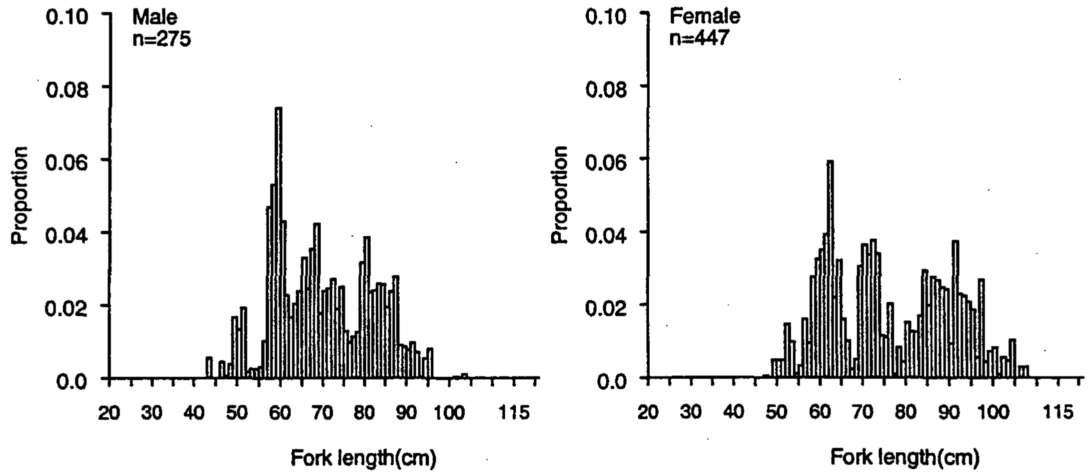

Figure B1: Length frequencies of males and females from the SKI 2 sampled catch, 2000.

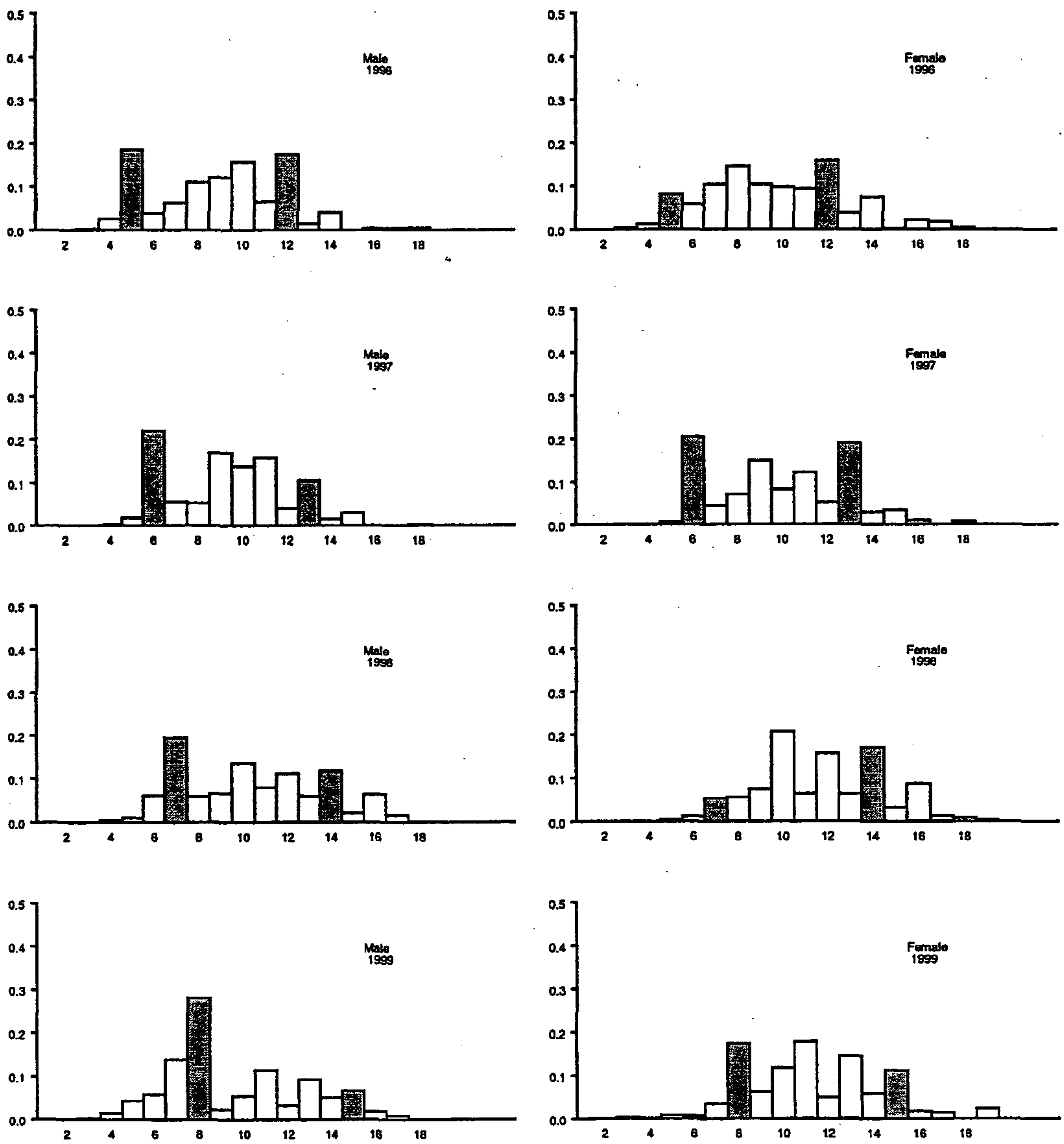

Figure B2: Age frequencies of gemfish from shed sampling catch-at-age data in SKI 1W, 1996–1999 (shaded bars show the 1984 and 1991 year classes).

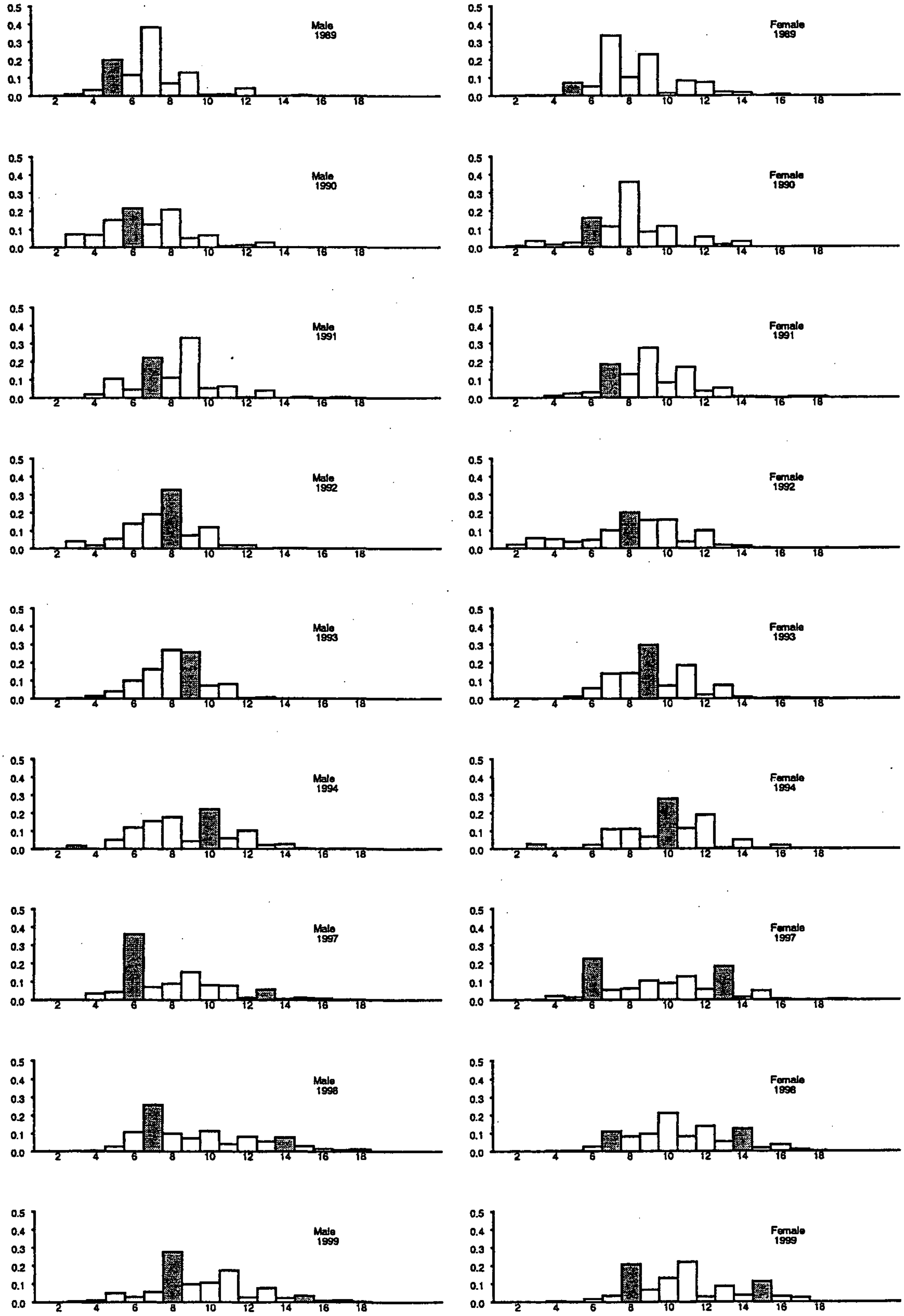

Figure B3: Age frequencies of gemfish from shed sampling catch-at-age data in SKI 1E, 1989–1994 and 1997–1999 (shaded bars show the 1984 and 1991 year classes).

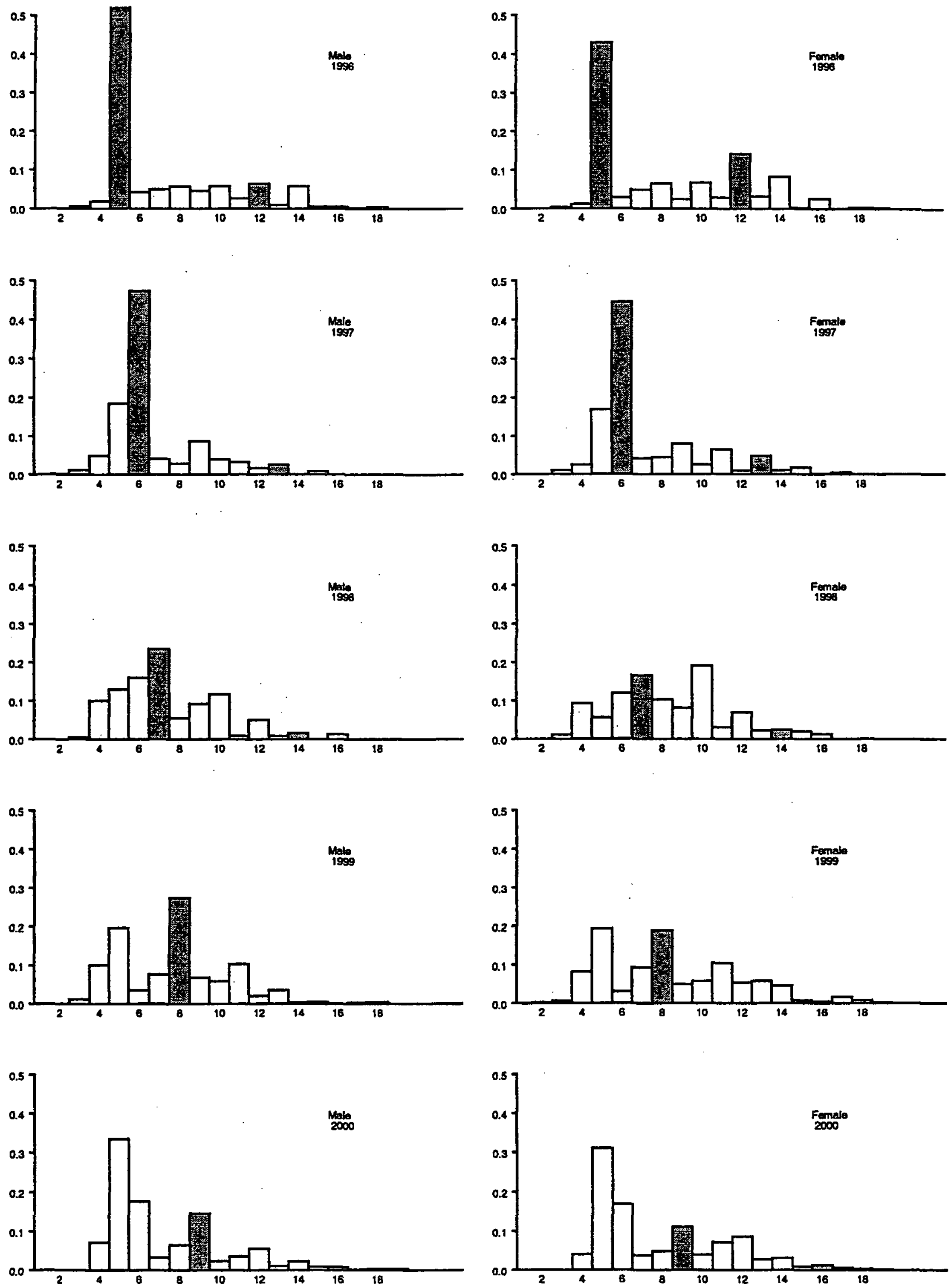

Figure B4: Age frequencies of gemfish from shed sampling catch-at-age data in SKI 2, 1996–2000 (shaded bars show the 1984 and 1991 year classes). (Note that ages and year classes have been presented so as to make them comparable to the SKI age data by assigning the upcoming birthday.)

Appendix C: Catch-per-unit-effort (CPUE) analyses

C1. INTRODUCTION

The SKI 1 fishery (Figure C1) is primarily a trawl fishery, targeting gemfish during the annual spawning migration. The fishery peaks during about April–June, although in some years there is a minor fishery in late August and early September as the mature fish return from the northern spawning grounds (Hurst et al. 1999b, 2000, Ingerson & Colman 1997).

The SKI 2 fishery (Figure C1) is primarily a target fishery, operating throughout most of the year — but not during June and July when the fish are assumed to have migrated north to spawn in the SKI 1 area (Hurst et al. 1999b, 2000, Ingerson & Colman 1997).

This analysis updates the previous analyses of catch effort data gemfish in SKI 1 & 2, by including data for the 1999–2000 fishing year. This analysis uses a similar methodology as for the previous analysis, and reported by Hurst et al. (2000).

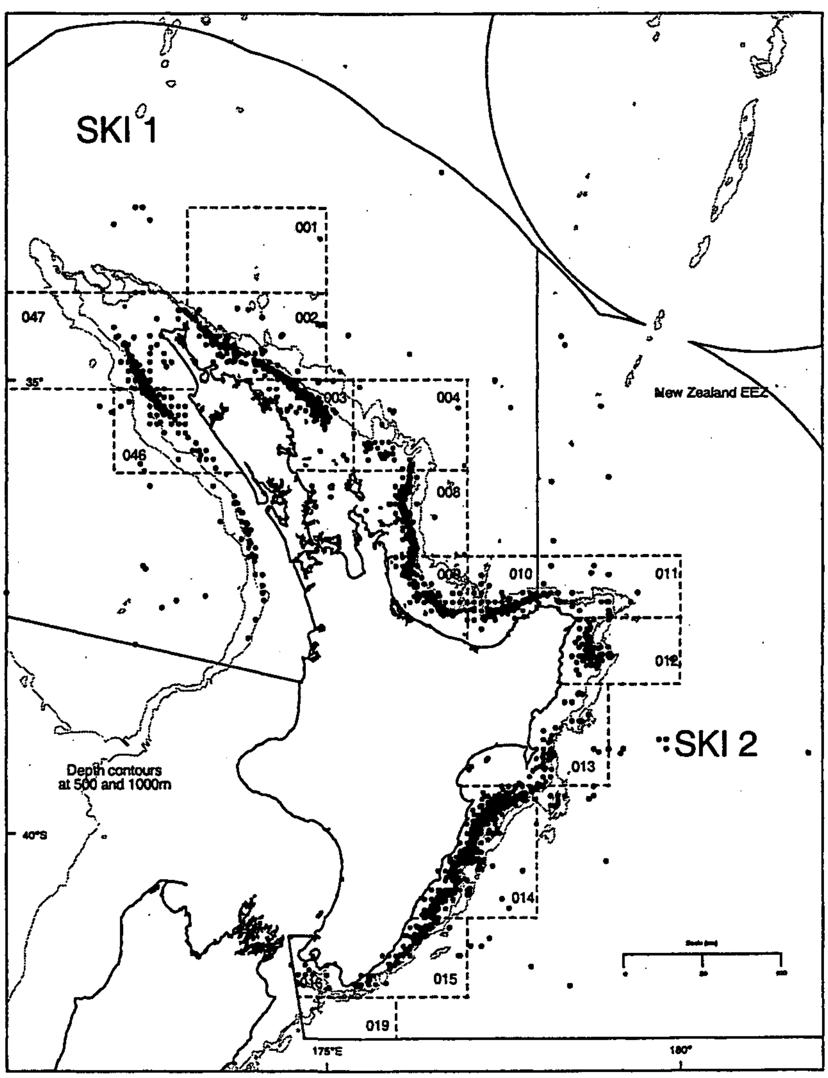

Figure C1: The Quota Management Areas and Statistical Management Areas for SKI 1 and SKI 2. Tow start positions for TCEPR recorded data for the 1989–90 to 1999–2000 fishing years are shown as dots.

C2. METHODS

C2.1 Description of the fishery

General aspects of the gemfish fisheries were investigated to ensure the patterns of catch and effort in the 1999–2000 fishing year were similar to previous years, Such changes, if any, may affect the analysis and interpretation of resulting CPUE indices from the catch effort data.

C2.2 The data and variables available for analysis

The catch effort data analysed comprised all recorded commercial catch effort data where gemfish was targeted using either bottom or midwater trawl gear in either SKI 1 or 2 between the 1989–90 and the 1999–00 fishing years. Further, that the data were recorded on the Ministry of Fisheries catch effort database systems before December 2000.

Both Trawl Catch Effort Processing Returns (TCEPR) and Catch Effort Landing Returns (CELR) records were included. TCEPR data were summarised by vessel day to allow the two data sets to be combined for analysis. The TCEPR records were not analysed separately, and no analysis of tow by tow data was conducted.

Table C1 describes the variables available (including those derived) from the combined TCEPR and CELR records. Most of the variables are self explanatory, but some require further definition. *Vessel* was a categorical variable with each vessel assigned its own category. However, those *Vessels* that recorded less than 50 records were grouped together. *Fishing day* was treated as a categorical variable comprising eight equally sized bins that spanned the range of days from the start of the fishing year.

Table C1: Description of variables available for the analysis the combined CELR and TCEPR records. Variables in bold are categorical variables.

Variable	Description
Listed	
Form number	Form number of the individual CELR or TCEPR records
Fishing year	Fishing year (from 1 October to 30 September)
Vessel	Unique vessel identification number
Start date	Date at the start of the tow
Fish stock	The fishery at the start of the tow, i.e., SKI 1 or 2
Method	Gear type used, i.e., bottom or midwater trawl gear
Duration	Duration of the tow (hours)
Statistical area	Statistical area at the start of the tow
Total catch	Total catch (in tonnes) of gemfish and bycatch species from the tow
Gemfish catch	Total catch (in tonnes) of gemfish
Nationality	The registered nationality of the vessel at the time of the tow
Vessel length	The overall length of the vessel in metres at the time of the tow
Vessel draught	The registered draught of the vessel in metres at the time of the tow
Vessel breadth	The registered breadth of the vessel in metres at the time of the tow
Vessel tonnage	The gross tonnage in metric tonnes of the vessel at the time of the tow
Vessel power	Power in kilowatts of the vessel engine
Vessel year built	Year of vessel built
Derived variables	
Fishing day	Number of days since start of the fishing year grouped in eight bins
CPUE	Catch (kg) per hour

C2.3 Data checking and validation

The catch effort data contained a number of possible recording and transcription errors — most in the form of missing data, invalid codes, or implausible values. Data for all areas were checked for such errors before the analysis. The process of checking, validating, and cleaning the data is similar to that described previously by Vignaux (1993), Dunn & Harley (1999), and Phillips (2001). In general, individual records for each of the areas were selected if they occurred within the area boundaries within the defined period. Tow records outside the defined area boundaries or time period were not investigated or otherwise validated, and hence were deleted.

All the variables for each record were checked for valid codes and values, and all variables were range checked. Variables with invalid codes or out of range values were visually compared with records from the same vessel on or around the time and date of the tow in question. Obvious transcription errors and recording errors were corrected, if possible. If no correction could reasonably be applied and the data were still considered highly improbable or had an invalid code, then the values were set to missing. Otherwise no change was made.

The error checked and corrected data sets provided the basis for fitting the standardised CPUE models.

C2.4 Calculation of standardised CPUE

Estimates of relative year effects (i.e., the CPUE indices) were obtained from a stepwise multiple regression method. Data were modelled using a lognormal model similar to that of Vignaux (1994). The number of zero catch records ranged from between 0 and 16% for each year and Statistical Area (see below). Zero tows were included in the regression as small positive values and were arbitrarily assigned a catch of 1 kg.

A forward stepwise multiple regression-fitting algorithm was employed (Chambers & Hastie 1991, Venables & Ripley 1994). The algorithm generates a final regression model iteratively and was implemented using the simple intercept model as the base model starting point. The reduction in residual deviance is calculated for each single term added to the base model. The term that results in the greatest reduction in the residual deviance is added to the base model, if this would result in a change of more than 2%. The algorithm then repeats this process, updating the base model until no more terms can be added (Dunn & Harley 1999) that would result in a change of at least 2%.

The stepwise algorithm also considered first order interactions terms. At each step, all first order interactions between variables selected up to that point were evaluated. As earlier, terms that resulted in a reduction of more than 2% in residual deviance were added to the model, and terms less than 2% increase in null deviance were deleted.

Fishing year was treated as a categorical value so that the regression coefficients of each year can vary independently. The relative year effects calculated from the regression coefficients represent the change in CPUE over time, all other effects having been controlled. We assume that the resulting CPUE index represents an index of abundance for gemfish. However, we do not attempt to validate the resulting CPUE indices as indices of abundance in any manner.

Vessel effects were incorporated into the analysis to allow for the likely differences in fishing power between vessels. Because the standardisation requires a time series of data to determine changes in abundance, such vessel effects need to be distinguished from the year effects. As with the previous analyses, the variable *Vessel* was assigned as a categorical variable, with each vessel assigned its own category unless there were less than 50 records, and then vessels were lumped together. As the primary interest in the model is an estimate of relative year effects, possible interactions with *fishing year* or *vessel* were not evaluated. Hence, we assume that the relative fishing power between vessels remains constant over the period of interest.

C3. RESULTS

C3.1 Description of the fishery

There has been a general decline in the target gemfish catch in both SKI 1 and SKI 2 to less than 50% of 1989–90 catches. The unstandardised catch rate (tonnes per trawl) has remained relatively constant since 1989–90 in SKI 1, and declined about 30% in SKI 2 (Table C2). The proportion of zero catches of gemfish while targeting increased until 1997–98, but has since decreased.

Table C2: Estimated gemfish target catch (tonnes), number of trawls (number of trawls), mean tonnes per trawl, and the percentage of zero catch records by bottom and midwater trawls recorded from CELR and TCEPR records for the 1989–90 to 1999–2000 fishing years in SKI 1 & 2.

	SKI 1				SKI 2			
Year	Catch (t)	Number of trawls	Tonnes per trawl	% zero catch	Catch (t)	Number of trawls	Tonnes per trawl	% zero catch
1989–90	945	1 168	0.81	5.70	608	697	0.87	5.22
1990–91	860	1 136	0.76	1.83	447	734	0.61	4.13
1991–92	737	1 412	0.52	6.80	931	1 310	0.71	3.42
1992–93	974	1 626	0.60	3.35	676	1 281	0.53	6.42
1993–94	955	884	1.08	4.15	790	1 350	0.58	7.71
1994–95	905	770	1.18	5.66	709	1 074	0.66	14.70
1995–96	636	977	0.65	8.37	612	1 315	0.47	12.72
1996–97	780	826	0.94	8.93	691	1 289	0.54	10.26
1997–98	501	815	0.62	14.43	370	879	0.42	16.36
1998–99	263	507	0.52	4.69	210	584	0.36	15.46
1999–2000	261	369	0.71	10.34	340	648	0.52	10.68

SKI 1 catch is almost all from bottom trawl gear, although since 1994–95 there has been about a 68% decrease in the catch by bottom trawl gear. In SKI 2, the catch from trawls with bottom trawl gear has fluctuated between about 200 and 800 t between 1989–90 and 1999–2000, while midwater catch has reduced to negligible amounts since the peak of 429 t in 1994–95 (Table C3).

The reporting of gemfish catch has gradually moved from CELR to TCEPR records since the early 1990s for both SKI 1 & 2 (Table C4). In addition, there is an increasing disparity between the total recorded landings of gemfish and the reported target catch of gemfish from TCEPR and CELR records (Table C4).

Most of the catch has come from nine statistical areas in SKI 1 (001, 002, 003, 004, 008, 009, 010, 046, and 047), and six statistical areas in SKI 2 (011, 012, 013, 014, 015, and 016). This has remained consistent since the early 1990s (Table C5).

C3.2 Estimated CPUE indices

Table C6 shows the final stepwise regression variables selected, by order of selection, for SKI 1. Table C7 shows the resulting CPUE indices, together with estimated 95% confidence intervals.

Table C3: Estimated gemfish target catch (tonnes) by trawl methods recorded from CELR and TCEPR records for the 1989–90 to 1999–2000 fishing years. All values have been rounded to the nearest tonne, with "0" indicating landings less than 0.5 t, and "-" indicating nil landings.

	SKI 1				SKI 2			
Year	Bottom pair	Bottom	Midwater	Total	Bottom pair	Bottom	Midwater	Total
1989–90	3	943	–	946	–	608	–	608
1990–91	–	860	0	860	–	447	–	447
1991–92	–	737	0	737	–	805	126	931
1992–93	–	974	0	974	–	606	70	676
1993–94	0	955	0	955	–	531	258	789
1994–95	0	905	–	905	–	280	429	709
1995–96	–	636	0	636	–	377	235	612
1996–97	–	780	0	780	–	560	131	691
1997–98	–	501	0	501	–	353	17	370
1998–99	–	262	1	263	–	209	1	210
1999–2000	–	259	2	261	–	332	7	339

Table C4: Estimated gemfish target catch (tonnes) of gemfish by all trawl methods combined listed on CELR and TCEPR records for the 1989–90 to 1999–2000 fishing years, with reported landings of gemfish (landings, from Table 2 above) and the estimated target gemfish catch as a percentage of reported gemfish landings (%). All values have been rounded to the nearest tonne, so "0" indicates landings less than 0.5 t.

	SKI 1					SKI 2				
Year	CELR	TCEPR	Total	Landings	%	CELR	TCEPR	Total	Landings	%
1989–90	681	264	945	1 230	77	608	0	608	1 043	58
1990–91	691	169	860	1 058	81	420	27	447	949	47
1991–92	506	231	737	1 017	72	632	298	930	1 208	77
1992–93	625	349	974	1 292	75	393	283	676	1 020	66
1993–94	299	657	956	1 156	83	185	605	790	1 058	75
1994–95	114	791	905	1 031	88	139	570	709	905	78
1995–96	28	608	636	801	79	114	498	612	789	78
1996–97	99	681	780	965	81	139	552	691	978	71
1997–98	15	487	502	627	80	27	344	371	671	55
1998–99	11	252	263	413	64	15	195	210	335	63
1999–2000	11	250	261	409	64	2	337	339	506	67

In total, four variables were selected by the stepwise multiple regression algorithm for SKI 1 with the model reporting a 33% reduction in residual deviance. *Vessel* was the variable that resulted in the most reduction of residual deviance (Table C6).

Table C7 shows the resulting CPUE indices for SKI 1, with 95% confidence intervals. There appears to be little change in 1999–2000 compared to the 1998–99 fishing year. Although the CPUE indices have declined from 1.0 in the 1989–90 fishing year to 0.13 in the most recent year. Plots of the CPUE indices are shown in Figure C2. The estimated indices were similar to those presented by Hurst et al. (2000), with both analyses having similar explanatory variables.

Figure C3 show diagnostic plots of the model fit, with plots of the residual fitted and observed values. The diagnostics show some departures from model assumptions (of normally distributed constant variance residuals) indicating the fit may be inadequate and the model could be improved. In particular, observations that were of zero catches, and included as small positive values, are clearly visible within the diagnostic plots.

Table C5: Estimated gemfish target catch by statistical area from CELR and TCEPR records for the 1989–90 to 1999–2000 fishing years . All values have been rounded to the nearest tonne, so "0" indicating landings less than 0.5 t and "–" indicating nil landings.

QMA	Stat.											Fishing year
	area	89–90	90–91	91–92	92–93	93–94	94–95	95–96	96–97	97–98	98–99	99–00
SKI 1	001	32	–	15	28	7	4	6	21	2	–	–
	002	6	4	14	50	39	37	81	27	6	5	4
	003	251	292	256	197	260	247	106	65	60	72	64
	004	2	–	2	58	11	6	3	7	4	0	0
	005	0	–	0	1	1	–	0	0	–	–	–
	007	3	–	–	–	–	–	–	–	–	–	–
	008	227	81	152	405	152	72	82	102	55	18	2
	009	273	242	186	115	33	17	25	31	15	8	3
	010	153	233	70	19	13	3	20	21	1	2	3
	042	–	–	2	–	–	–	0	–	0	0	0
	045	–	–	–	–	–	–	4	0	0	0	0
	046	0	–	–	1	116	90	90	214	175	72	120
	047	0	8	42	100	324	428	223	292	184	87	67
	048	–	–	–	–	–	0	0	0	–	–	–
	101	0	–	–	–	–	1	–	–	–	3	–
	102	–	–	–	1	–	–	–	–	0	–	–
	104	–	–	–	–	–	–	1	0	–	–	–
	106	–	–	2	–	0	–	–	–	–	–	–
	107	–	–	–	–	–	–	19	–	0	–	–
SKI 2	011	1	1	13	10	3	3	3	1	6	7	2
	012	–	11	8	0	1	16	116	138	20	11	31
	013	31	67	227	114	281	423	212	211	140	88	170
	014	465	252	550	432	470	204	212	316	199	96	135
	015	105	113	100	119	31	61	67	25	5	9	2
	016	5	2	32	0	3	2	2	–	–	0	–
	201	–	–	–	2	1	–	1	0	–	–	0
	203	–	–	–	–	0	0	–	–	–	–	5
	204	–	0	1	4	0	0	0	–	1	0	3
	205	–	4	–	–	0	0	0	–	–	–	–

Table C6 shows the final stepwise regression variables selected, by order of selection for SKI 2. The same four variables that were selected for SKI 1 were selected by the stepwise multiple regression algorithm for SKI 2, with a 23% reduction in residual deviance. *Vessel*, again, was the variable that resulted in the most reduction of residual deviance.

Table C7 shows the resulting CPUE indices for SKI 2, with 95% confidence intervals. There is a slight increase in 1999–2000 compared with 1998–99. However, as for SKI 1, the CPUE indices have declined from 1.0 in 1989–90 to 0.12 in the most recent year. Estimated indices from the 2001 model (Figure C4) and from the 2000 model (Hurst et al. 2000) are similar, except for the estimated index in 1998–99. Hurst et al. (2000) estimated the value of this index as 0.07. Note that the estimated value of the index for 1999 for SKI 2 differs more than would be expected from values previously reported (i.e., 0.07 in 1999). This was due to a calculation error in the CPUE indices reported by Hurst et al. (2000).

Figure C5 show diagnostic plots of the model fit for SKI 2, with plots of the residual fitted and observed values. The diagnostics show some departures from model assumptions (of normally distributed constant variance residual errors) indicating the fit may be inadequate and the model could be improved.

Table C6: Variables selected by the stepwise multiple regression algorithm for SKI 1 and SKI 2, with the cumulative reduction in residual deviance as a percent of the null deviance.

SKI 1		SKI 2	
Variable	%	Variable	%
Vessel	17.33	*Vessel*	11.33
Fishing year	21.08	*Fishing year*	16.32
Stat. Area	26.01	*Day*	19.46
Day	32.95	*Stat. area*	23.10

Table C7: Estimated CPUE indices with 95% confidence intervals for SKI 1 and SKI 2.

	SKI 1		SKI 2	
Year	Index	95% C.I.	Index	95% C.I.
1989–90	1.00	–	1.00	–
1990–91	0.94	0.75–1.19	0.74	0.55–1.00
1991–92	0.38	0.30–0.48	0.53	0.41–0.70
1992–93	0.51	0.41–0.64	0.29	0.23–0.38
1993–94	0.43	0.34–0.55	0.24	0.19–0.32
1994–95	0.27	0.21–0.35	0.14	0.10–0.19
1995–96	0.18	0.14–0.23	0.14	0.10–0.19
1996–97	0.26	0.20–0.32	0.13	0.10–0.18
1997–98	0.15	0.12–0.20	0.07	0.05–0.10
1998–99	0.17	0.13–0.23	0.11	0.07–0.15
1999–2000	0.13	0.10–0.19	0.12	0.09–0.18

C4. CONCLUSIONS

In both the fisheries (SKI 1 & 2), the results of the two models are very similar. The CPUE indices derived from both models indicate that there has been a substantial, and very similar, decline in the standardised catch rate in both areas since 1989–90. The most recent indices suggest that abundance has remained low.

Small increases in the SKI 2 indices over the last two years may possibly be attributed to an increase in the numbers of 4 and 5 year old fish recruiting to the fishery (i.e., recruitment from the 1996 and 1997 ages classes). This conjecture appears to be somewhat supported by the appearance of these year classes in the SKI 2 commercial catch-at-age data.

There has been a gradual decline in the recording of gemfish catch using CELR records, and a corresponding increase in catch recorded using TCEPR records. In future, it may be useful to develop a shorter time series using just the TCEPR records.

A more thorough analysis on the gemfish fishery may also need to be completed, as there are possible changes in the fishery due to the reduced gemfish catch, which may for example influence targeting, thus affecting on the resulting estimates of the CPUE indices.

Residual diagnostics provide a method for verifying model assumptions, and can provide some evidence for validation that the estimated year effects are reliable. The diagnostics for the models suggest the fits may not be adequate and could be improved.

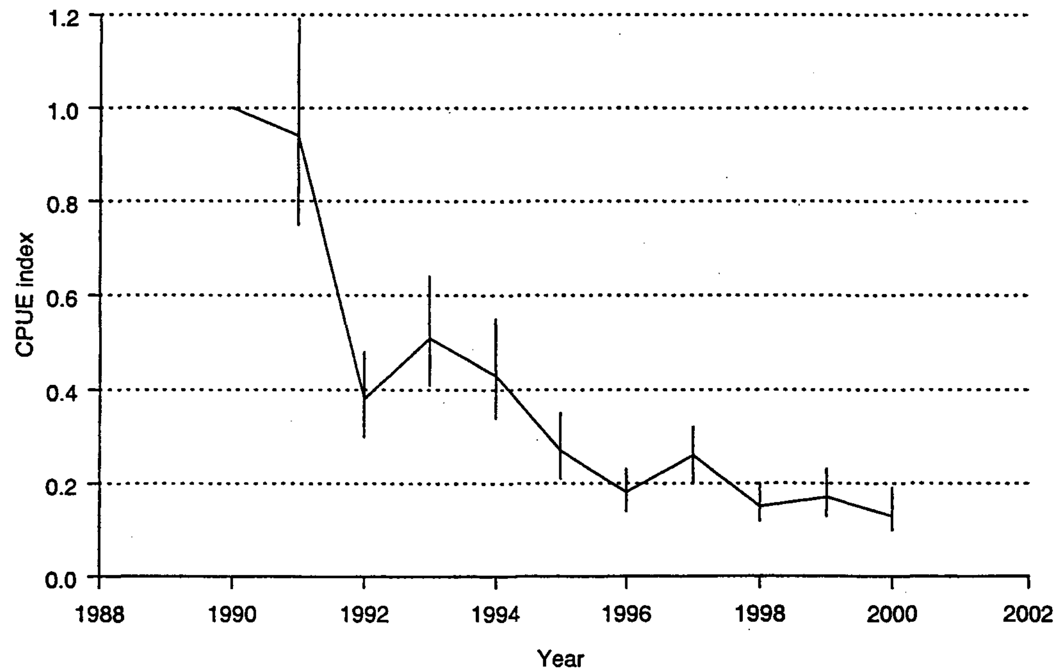

Figure C2: Relative year effect indices and 95% confidence intervals (vertical bars) for the SKI 1 target fishery.

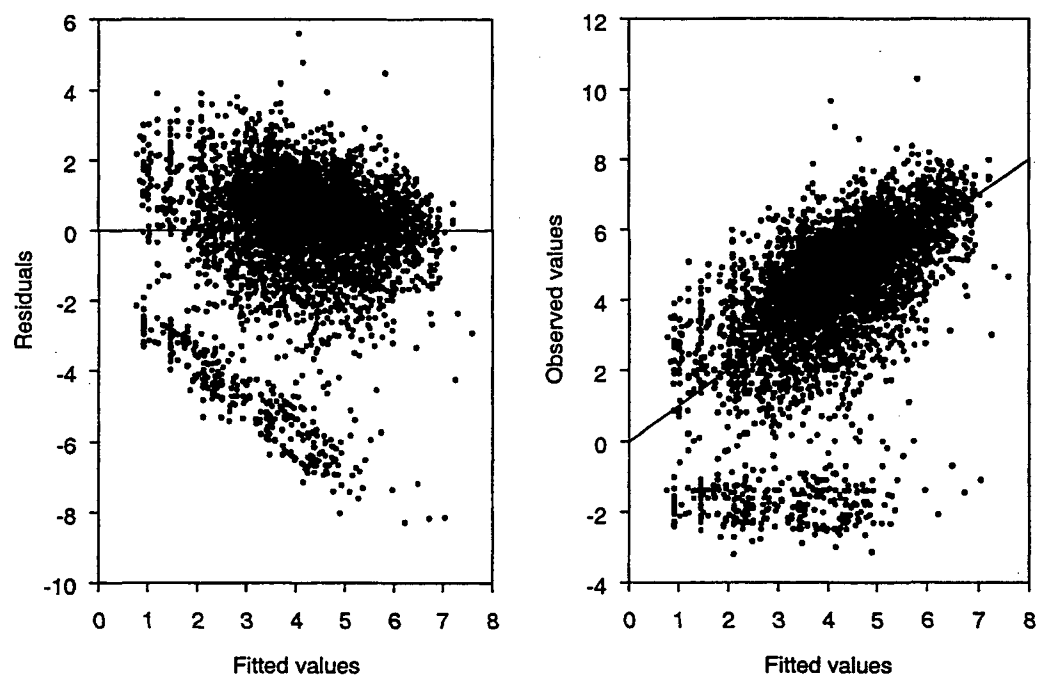

Figure C3: Diagnostic plots (log scale) of the lognormal model for the SKI 1 target fishery (left) fitted values versus residuals, and (right) fitted values versus observed values.

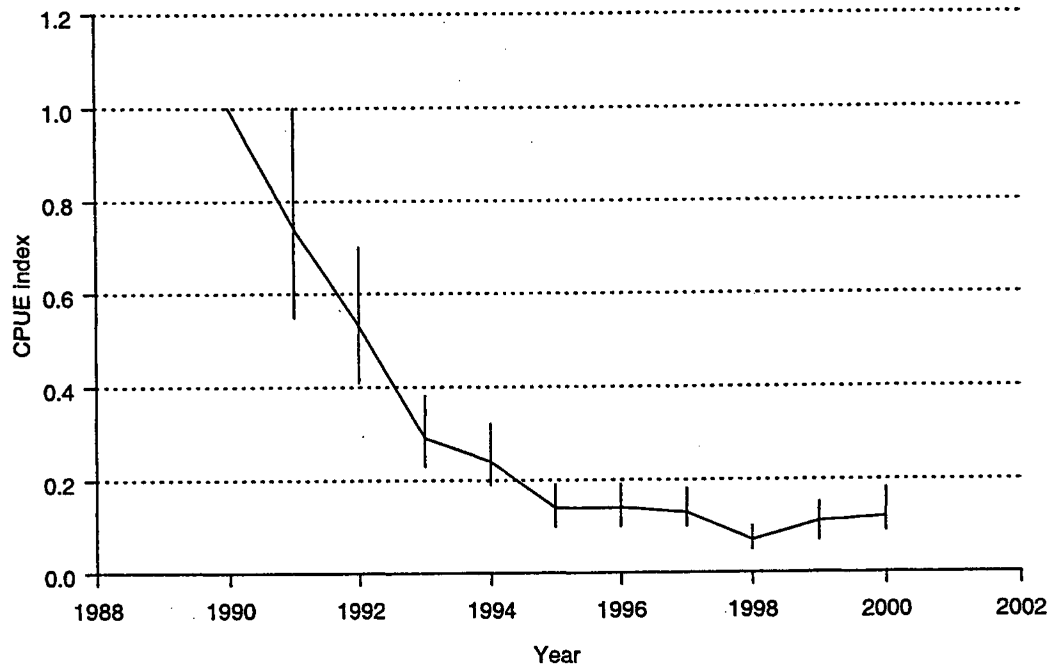

Figure C4: Relative year effect indices and 95% confidence intervals (vertical bars) for the SKI 2 target fishery.

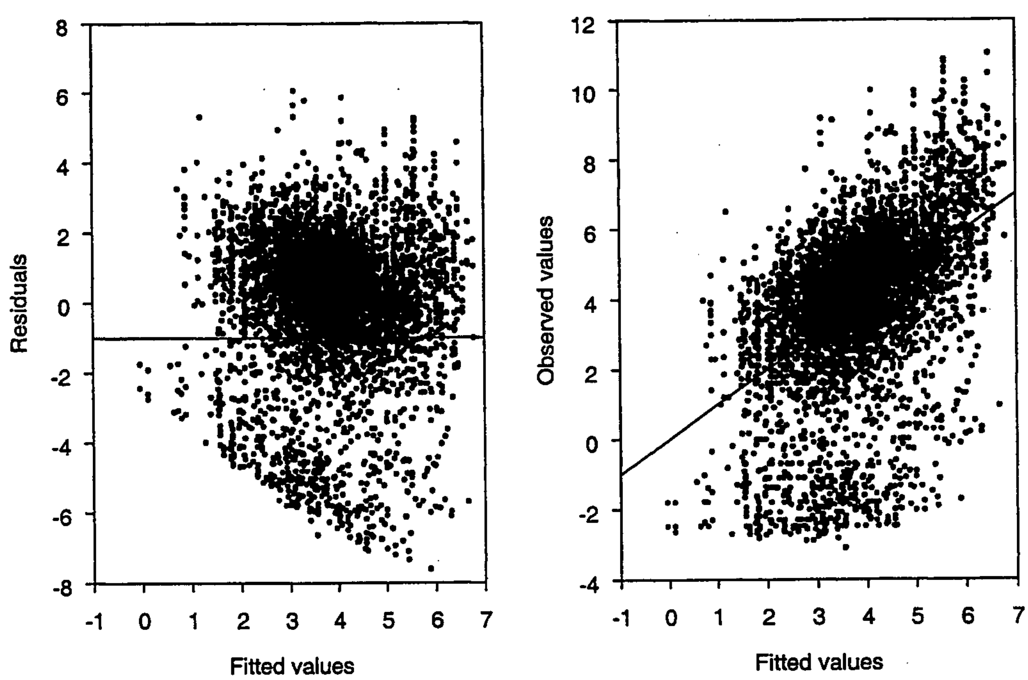

Figure C5: Diagnostic plots (log scale) of the lognormal model for the SKI 2 target fishery (left) fitted values versus residuals, and (right) fitted values versus observed values.