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EXECUTIVE SUMMARY

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This report provides the results of the first model-based stock assessment of red gurnard stocks GUR 1 and GUR 2. For stock assessment, GUR 1 was treated as two separate stocks and divided at North Cape into western (GUR 1W) and eastern (GUR 1E) sections.

Catch and effort data have been extracted, the various fisheries characterised, and a catch history for modelling collated. Relative abundance indices for 1990 to 1997 are derived from catch per unit effort for each of the three stocks. Trawl survey indices of adult (2 year old and over) and pre-recruit (1 year old) abundance from the west coast North Island, Hauraki Gulf, Bay of Plenty, and east coast North Island are standardised and tabulated. Otoliths from four trawl surveys have been read, growth curves developed, and proportion-at-age has been estimated. Biological parameters have been estimated and are presented for each area.

Modelling used the MIAEL stock reduction approach to estimate biomass and yields (MCY). For each of the three stocks, models were fitted to the adult relative abundance indices derived from the trawl surveys, assuming deterministic recruitment, to estimate B_0 and B_{mid99} (mid-season spawning stock biomass for the 1998–99 fishing year). Catch per unit effort indices were fitted as sensitivity analyses. Model runs incorporating the pre-recruit indices and proportion-at-age data were also completed to evaluate whether these data produced more precise assessments.

The estimate of B_0 for GUR 1W is about 15 900 t, with a performance index of only 11%. The estimate of B_{mid99} is about 70% of B_0, and has a much higher performance index of almost 60%. The stock trajectory is increasing, suggesting that current catch levels are sustainable. A model run incorporating available age data was less precise (i.e., had wider bounds and lower performance indices), and produced a B_0 estimate of 27 000 t, but still indicated that the stock was currently above B_{MSY}.

Estimates of virgin and current biomass for GUR 1E are highly uncertain without the inclusion of any age data. Trawl survey indices of abundance for GUR 1E are variable but appear to have declined since the early 1980s, whilst CPUE has declined since 1990. The incorporation of age data markedly improved the assessment, and indicated that B_0 was about 31 000 t, and current biomass is about 60% of B_0. Current catch levels in GUR 1E are probably sustainable, at least in the short term.

Estimates of virgin and current biomass for GUR 2 are highly uncertain because they have extremely low performance indices (often less than 1%). The trawl survey and CPUE indices have been reasonably flat since the early 1990s, and current catch levels there are probably sustainable, at least in the short term. No useful age data are currently available for GUR 2. Because of this, the assessment for GUR 2 was rejected by the Working Group and was not considered further for management.

1. INTRODUCTION

Red gurnard (*Chelidonichthys kumu*) is found throughout the central tropical and temperate Indo-Pacific coastal waters from Japan to New Zealand. In New Zealand waters it is most abundant north of the subtropical convergence, occurring mostly in depths of less than 55 m, but occasionally to greater than 150 m (Elder 1976).

Red gurnard have been landed as a bycatch of the inshore bottom trawl fleet in most areas around New Zealand since the 1930s. Total annual landings steadily increased to 2000 t by 1955 and peaked at almost 4000 t in 1965 (Blackwell 1988). From then, until the introduction of the QMS in 1986, landings were erratic, averaging about 3000 t. A TACC of 4000 t was set in 1986 which has gradually increased through quota appeals and the adaptive management programme to its current level of 5300 t. However, landings have remained constant since 1986, averaging about 3000 t.

Around the North Island, red gurnard landings have followed a similar pattern to landings overall (Blackwell 1988). Landings on the west coast, Hauraki Gulf, and Bay of Plenty peaked in the early 1980s and then declined, whereas landings on the east coast peaked in the mid 1960s and have since declined. Landings in both Fishstocks (GUR 1 and GUR 2) are well below the current TACC.

Throughout New Zealand, red gurnard are mainly taken as a bycatch of trawl fisheries directed at snapper, trevally, John dory, flatfish, and tarakihi, but in some areas — notably off Mahia, in Pegasus Bay, and on west coast South Island — there are also significant target trawl fisheries. A small amount (up to 15% of the catch) of red gurnard is also caught by longline and set net (Annala *et al.* 1998).

Very little directed research has been carried out on gurnard stocks in New Zealand waters since the study in the Hauraki Gulf by Elder (1976). Blackwell (1988) reviewed the fishery and available biological data, and presented MCY estimates. More recently, as part of the adaptive management programme, some research has been carried out on gurnard stocks GUR 3 and GUR 7, from the east coasts and west coasts of the South Island respectively. Analysis of catch per unit effort data was carried out by Vignaux (1997), and samples of fish from recent trawl surveys of those areas were aged by Sutton (1997). However, previous estimates of MCY are based on average catches for all stocks, and there has been no modelling of the stocks on which to base estimates of biomass and yield.

The aim of the current research was to draw together data for gurnard in QMAs 1, 2, and 9 from a variety of sources for the purposes of stock assessment. Catch and effort data have been extracted, the various fisheries characterised, and a catch history for modelling purposes has been collated. Relative abundance indices for 1990 to 1997 are derived from catch per unit effort for each of the three areas. Trawl survey indices of adult and pre-recruit abundance from the west coast North Island, Hauraki Gulf, Bay of Plenty, and east coast North Island are standardised and presented separately for the first time. Otoliths from several trawl surveys have been read, growth curves developed, and proportion at age has been estimated. Biological parameters have been estimated and compiled for each area. Modelling has been carried out using the MIAEL approach (Cordue 1993, 1996) to estimate biomass and yields (MCY).

2. THE GURNARD FISHERY

2.1 Commercial catches

The catch histories for GUR 1 and 2 were collated for 1931 to 1996–97 (Table 1). The catch history for GUR 1 was divided into east and west of North Cape. For 1931 to 1984, the catches were divided on the basis of the port of landing. For 1984–85 to 1996–97, the ratio of catches from west and east in

GUR 1 was assumed to be 40:60 based on the average of the ratio in earlier years and on the ratios of estimated landings from the TCEPR and CELR forms for 1989–90 to 1995–96.

GUR 1W (west of Northland)

The west coast North Island (GUR 1W) fishery developed in the 1950s and annual catches rose steadily during the 1960s and 1970s, peaking in 1981 at almost 1500 t before dropping back to about 600 t at the introduction of the QMS in 1986. Since then annual catches have been reasonably stable, averaging about 450 t per year.

The fishery is primarily a bycatch of the bottom trawl fishery for snapper and trevally. However, about 15% of the red gurnard catch is reported as targeted and significant amounts are also caught in the trawl fishery for tarakihi (Table 2). The fish are taken throughout QMA 9, with no obvious area preferences.

GUR 1E (northeast North Island)

The gurnard fishery in GUR 1E includes East Northland, the Hauraki Gulf, and the Bay of Plenty (Blackwell 1988). The Hauraki Gulf fishery developed in the early 1930s and catches rose steadily peaking at about 600 t in 1965 and again in 1982. Landings were low from Bay of Plenty until the 1970s, and from East Northland until the early 1980s. Total catch from all three areas peaked at about 1000 t for the years 1982 to 1986. However, after the introduction of the QMS catches dropped to 700 t and have since been reasonably stable at that level.

Red gurnard are taken as a bycatch of the bottom trawl fisheries for a variety of species including snapper, tarakihi, John dory, trevally, barracouta, and flatfish (Table 2). About 13% of the red gurnard catch is reported as targeted, and is taken from throughout QMA 1. Gurnard are reported as a bycatch of the snapper and John dory fisheries reported from East Northland and the Hauraki Gulf and as a bycatch of the snapper and tarakihi fisheries and from the Bay of Plenty.

The TAC for GUR 1 was originally set at 2010 t based on the 1982 landings. This has gradually increased to 2287 through quota appeals. Recent landings (combined east and west) have averaged about 50% of the TAC.

GUR 2 (Cape Runaway to Cook Strait)

The east coast North Island (GUR 2) fishery developed in the early 1930s and catches rose steadily to a peak of almost 900 t in 1968 before declining to about 500 t in 1986. Although the TAC was initially set at 610 t in 1986 and later increased to 725 t, catches have averaged less than 600 t during that time.

Red gurnard are taken as a bycatch of the bottom trawl fisheries for a variety of species including tarakihi, trevally, snapper, barracouta, and flatfish (*see* Table 2). About 15% of the red gurnard catch is reported as targeted. Gurnard appear to be targeted mainly off the Mahia Peninsula and in Hawke Bay.

2.2 Catch history split into pre-spawning and spawning season

The structure of the MIAEL stock assessment model allows for the input of catch split into pre-spawning and spawning season segments. In the assessment reported here, the Working Group chose to model gurnard assuming an instantaneous spawning season with all catch taken in the pre-spawning season. However, splitting catch histories by season was investigated, and the conclusions are presented here for possible future use.

Red gurnard have a very long spawning season extending from December to March (Elder 1976). It was not possible to estimate the proportion of the annual catch taken in the spawning season for all years in the fishery. Instead the mean proportion of the catch taken during the spawning season over the past 8 years was calculated and this proportion was then applied to all years.

Monthly landings reported from the QMRs by QMA since 1989–90 were analysed to determine the proportion taken during the spawning season. For GUR 1 as a whole, between 33% and 46% (mean 36%) of the annual catch was taken during the spawning season. On this basis, it is suggested that a mean value of 35% be applied to the total fishing year catch for all years and both areas (GUR 1E and GUR 1W) to derive the spawning season catch. For GUR 2, between 24% and 37% (mean 31%) of the annual catch was taken during the spawning season. On this basis, a mean value of 30% should be applied to the total fishing year catch for all years.

2.3 Recreational catches

Red gurnard is an important species for recreational fishing interests because of its wide distribution in shallow coastal waters. Recreational harvests for GUR 1 and GUR 2 have been estimated at between 150–250 t and 50–125 t respectively from regional recreational fish surveys, and at between 100–120 t and 10–20 t from national diary surveys (Annala *et al.* 1998).

3. CPUE ANALYSIS

The following section describes the CPUE analyses carried out for bottom trawling of gurnard in GUR 1 East (east coast Northland), GUR 1 West (west coast Northland), and GUR 2 (Cape Runaway to Cook Strait) from 1989–90 to 1996–97. Three CPUE indices were calculated to indicate changes in stock size of gurnard. They were the raw CPUE, standardised analysis of success rate, and standardised analysis of the catch rates when fishing was successful. The last two indices were also combined following Vignaux (1997).

3.1 *Definition of the gurnard fisheries*

A major decision in this CPUE analysis was how to define the gurnard fishery in each of the three areas. Gurnard around northern New Zealand is part of the multi-species inshore fishery, a high proportion of both the catch *and* effort is reported against target species other than gurnard. However, the CPUE analysis needed to include both successful attempts to catch gurnard and unsuccessful attempts. Therefore, such an analysis needed to include vessel-days when there was an appropriate target species from the multi-species fishery, but no gurnard caught.

Examination of data for all vessel-days when gurnard was reported in the catch showed that gurnard was caught by bottom trawl against 42 different target species in GUR 1 and GUR 2. For many of these target species the catch was very small, or clearly an error; records for these target species were excluded.

Of the target fisheries in each area that consistently reported gurnard catch, the proportions of the total gurnard catch they accounted for during 1989–97 were compared (*see* Table 2). Target species which accounted for a substantial proportion of the total catch in each area were considered to collectively define the gurnard fishery in that area. Note that (i) barracouta was excluded as the gurnard bycatch varied considerably from year to year, probably due to the changing geographical distribution of barracouta rather than gurnard abundance (NIWA, unpublished data), and (ii) flatfish was excluded from the GUR 2 analysis because plots of the raw CPUE (mean kg/day) by target species showed the trend in CPUE to be different from bycatch of other target species.

3.2 The catch-effort data

All records for the chosen target species were extracted from the Catch, Effort and Landing Returns (CELR) and Trawl Catch, Effort and Processing Returns (TCEPR). Most data (more than 70%) are from the CELR database, i.e., catch and effort reported by vessel-day. Therefore to carry out the CPUE analysis TCEPR data (reported as catch and effort by tow) was summarised to the vessel-day format.

Records were included in the analysis if they were from the inshore statistical areas of their respective QMAs, and the areas were not harbours or closed to bottom trawling (Table 3). Some 700 records reported a gurnard catch in offshore statistical area 001, but these are apparently a confusion in reporting between QMA 1 and statistical area 001 (A. Langley, pers. comm.) and were therefore also excluded.

Records were also excluded from the analysis if they had more than 10 tows per day (462 records) or total trawling time was longer than 24 hours per day (986 records). Missing vessel data led to 24 records being excluded from the analysis. Vessel length was missing for so many vessels that 2978 records were affected. Because of the large number of records affected it was decided to exclude vessel length from the list of predictor variable in the models.

The definition of an unsuccessful day's fishing is compromised to an unknown degree by the requirement to record only the top five species (by weight) caught.

3.3 Results of standardised regression analyses

The analyses of success rate and catch rate were each standardised using a stepwise multiple regression technique (Vignaux 1994a) to remove the effects of other explanatory (predictor) variables.

The success rate analyses used a binomial model in which predictor variables were regressed against successful (denoted as 1) or unsuccessful (denoted as 0) vessel-day. A vessel-day was considered unsuccessful if it had no reported catch of gurnard. Note that only the top five species caught by weight are reported in the catch-effort data, so an unsuccessful day does not necessarily mean that no gurnard were caught.

The catch rate analyses used a log-linear model in which the predictor variables were regressed against log (catch per day) for all vessel-days on which a catch of gurnard was reported.

Predictor variables used in the analyses are described in Table 4. Note that the interaction of area and target was introduced to each model only if, and after, *both* variables had been chosen by the model as having explanatory power. Variables were included in the log-linear models of catch rate if they improved the R^2, i.e., the explanatory power of the model, by more than 1%, or until fishing year was included as a variable. Variables were included in the binomial models of success rate if they improved the explanatory power of the model by more then 1%, or until fishing year was included in the model.

GUR 1W

Stepwise log-linear and binomial regression analyses used all vessel-days in GUR 1 West that targeted snapper, trevally, gurnard, and tarakihi. A summary of catch, effort, and raw CPUE is given in Table 5. The proportion of unsuccessful days fluctuated between 20% and 31%. Raw CPUE (kg per vessel-day) of gurnard increased by 80% between 1989–90 and 1992–93, after which it fluctuated between 193 kg/day and 270 kg/day.

A comparison of predictor variables selected into the models is given in Table 6. The log-linear model of catch rate on successful vessel-days was able to explain only 7.5% of the variance in log (kg/vessel per day). The relative year effects from each of the models and the combined indices (*after* Vignaux 1997) are given in Table 7 and Figure 1. The relative year effects from both the linear and binomial models were essentially flat between 1989 and 1997. Similarly, the combined index showed no trend.

GUR 1E

Stepwise log-linear and binomial regression analyses used all vessel-days in GUR 1 East that targeted snapper, tarakihi, John dory, gurnard, and trevally. A summary of catch, effort, and raw CPUE is given in Table 8. The proportion of unsuccessful days was high and fluctuated between 35% and 60%. Raw CPUE (kg per vessel-day) of gurnard dropped from 48 kg/day in 1989–90 to 20 kg/day in 1996–97.

A summary of the relative importance of predictor variables selected into the models is given in Table 9. The log-linear model of catch rate on successful days explained 24% of the variance in log (kg/day). The relative year effects from each of the models and the combined indices (*after* Vignaux 1997) are given in Table 10 and Figure 2. The relative year effects from the linear model of catch rate on successful days declined steadily between 1989 and 1997 to 43% of its 1989 value.

The indices from the binomial model of proportion of unsuccessful days were stable during the first 4 years then increased to 3.3 times the 1989 value (Table 10 and Figure 2), i.e., a day's fishing was three times more likely to report a zero catch of gurnard.

The combined index reflects the steady decline in the catch rate reported on successful days combined with the large increase in unsuccessful days, thereby suggesting a greater decline than is seen in the raw CPUE.

GUR 2

Stepwise log-linear and binomial regression analyses were used all vessel-days in GUR 2 that targeted gurnard, tarakihi, trevally, and snapper. A summary of catch, effort, and raw CPUE is given in Table 11. The proportion of unsuccessful days was relatively stable at about 30%. Raw CPUE (kg per vessel-day) of gurnard showed a slight downward trend from 135 kg/day in 1989–90 to an average of 116 in 1996–97.

A summary of the relative importance of predictor variables selected from the models is given in Table 12. The log-linear model explained 21% of the variance in log (kg/day). The relative year effects from each of the models and the combined indices (*after* Vignaux 1997) are given in Table 13 and Figure 3. The relative year effects from the linear model of catch rate on successful days declined steadily between 1989 and 1997 to 73% of the 1989 value.

The indices from the binomial model of proportion of unsuccessful days decreased by 35% during the first 3 years then increased steadily, to just above the 1989 value (Table 13 and Figure 3), i.e., in 1996–97 a day's fishing was 10% more likely to report a zero catch of gurnard than in 1989–90.

The combined index also shows a slight downward trend reflecting the increase in unsuccessful fishing days and the decline in catch rate on those days that were successful.

3.4 Discussion of CPUE analysis

In each of the three areas the raw, log-linear, and combined CPUE indices send a similar signal about the stock, and the influence of the binomial indices of unsuccessful fishing are appropriately reflected in the combined indices. For GUR 1E, there was a large increase in the index of unsuccessful fishing, and also a steady decline in the raw CPUE and index of catch rates. The combined index had dropped to just 22% of its 1989 value by 1996–97. For GUR 1W, all indices fluctuated and showed no overall trend. For GUR 2, there was a downward trend in the index of catch rates and a fluctuating index of unsuccessful fishing, resulting in a slight downward trend in the combined CPUE index.

Many factors that may affect CPUE have changed in these fisheries over the years but could not be included in these analyses as possible predictor variables. In the mid 1990s in GUR 1 there was a compulsory increase in mesh size from 100 mm to 125 mm; GUR 2 has a voluntary agreement to increase mesh size and various mesh sizes are used in the fishery but not recorded with catch-effort data; in GUR 2 there was an industry agreement not to target snapper in 1992; and in GUR 1E there were substantial cuts to the snapper TACC in 1992–93 and 1995–96. Changes that take place abruptly in a single fishing year are not adequately accounted for in these models.

A major problem in estimating the binomial index for these analyses was defining an unsuccessful days fishing. Gurnard is a ubiquitous species in these areas, and particularly in GUR 1 is almost always caught in an inshore tow by a bottom trawl. However, only the top five species caught (by weight) are recorded on the catch-effort form. The very high proportion of unsuccessful days (20–60%) estimated by our definition of the fishery is not considered to represent actual catches. This loss of precision in catch estimates as catch rates drop towards zero is not quantifiable, and may or may not be consistent. The result is a negative bias in the indices of catch rate, a positive bias in the indices of unsuccessful fishing, and a compounded negative bias in the combined indices of abundance. Any effect on the trends seen is unknown.

4. AGE AND GROWTH

4.1 Methods

Red gurnard otoliths were collected randomly during trawl surveys conducted by R.V. *Kaharoa* in the Hauraki Gulf (KAH9212 and KAH9411), west coast North Island (KAH9410 and KAH9615), and Bay of Plenty (KAH9601). Total length, measured to the nearest whole centimetre below actual length, and sex were recorded for all fish from which otoliths were extracted. Otoliths were cleaned and stored dry in paper envelopes.

Otoliths were read and processed following the methodology outlined for red gurnard by Sutton (1997). Because of the difficulty of embedding and processing the smaller gurnard otoliths they were initially read whole. Any otoliths for which there was some doubt over the age were then embedded in epoxy, sectioned, and read under reflected light. Age estimates were determined by counting the number of complete annuli. The annulus is defined as the hyaline zone, or the zone of slower growth, that appears as a dark zone under reflected light. Most otoliths were collected during October and November and had wide opaque zones at the edge of the otolith, although occasionally a narrow hyaline zone had begun to form. To maintain consistency between surveys, a birthday of 1 October was assumed for the fish. Therefore, 1 was added to the age estimate of all those fish caught during October and November that had an opaque zone at the edge of the otolith.

To check consistency with modes in the length frequency data, and consistency between readers, otoliths from a sample of small North Island fish were read whole, together with a sample of sectioned otoliths originally read by Sutton (1997). There was good agreement between the ages from the whole otoliths and the estimated age of the fish from the modes in the length frequency data. There was also good agreement with Sutton's readings.

The number of otoliths read by sex, area, and year are given in Table 14. Age-length keys were derived for each sex, area, and year, except Bay of Plenty because of low sample sizes. The age distribution of red gurnard in each of the Hauraki Gulf and west coast North Island surveys was constructed from the scaled length frequency distribution and the appropriate age-length key.

4.2 Growth curves

Growth curves were fitted to the otolith ages using the non-linear multivariate secant parameter estimation procedure (SAS Institute 1988). Growth curves were computed separately for males and females for each of the Hauraki Gulf and east coast North Island. No otoliths were collected from small fish (under 20 cm) from the Hauraki Gulf. The resulting growth curve did not fit the early ages very well and the estimates of t_0 of −0.45 and −1.44 for males and females respectively were unrealistically low. To enable a more realistic growth curve for the Hauraki Gulf the length of 1 year old fish was assumed to be 15.5 cm (from the first mode of the length-frequency data). The growth curves are shown by area and sex in Figure 4, and the von Bertalanffy growth parameters are given in Table 15. The growth estimated in the present study for the Hauraki Gulf is faster than that from Elder's composite Hauraki Gulf growth curve reported in Sutton (1997), but is slower than gurnard growth rates in the Firth of Thames (Elder 1976).

5. TRAWL SURVEYS

5.1 Biomass estimates

A series of trawl surveys of the Bay of Plenty, Hauraki Gulf, west coast North Island (WCNI), and east coast North Island (ECNI) have been carried out by R.V. *Kaharoa*. The survey design, stratum areas, and objectives of some of the earlier surveys have been summarised by Langley (1994) and Francis *et al.* (1995). Although the approach used was very similar between years, Francis *et al.* (1995) noted that there were progressive alterations to the net used on the Hauraki Gulf surveys between 1988 and 1990, which resulted in greater headline heights and doorspread during the latter half of the time series. The WCNI, Bay of Plenty, and Hauraki Gulf surveys used a 60 mm mesh codend, and the ECNI surveys used one of 100 mm. The WCNI surveys included QMAs 8 and 9, and these areas were considered separately.

Biomass estimates from all the areas were obtained using the NIWA Trawlsurvey Analysis Programme (Vignaux 1994b). A number of steps were taken to ensure standardisation between surveys. These included standardising the stratum areas and total survey areas for each time series, estimating doorspread (from warp length or depth) for tows where doorspread had not been measured, using length-weight relationships appropriate for that season and area, calculating catch weight from length frequency data when weights were not available, and excluding stations with poor gear performance, or where fish were present but no catch or length frequency data were available. Details of the parameters used for calculating the biomass and scaled length frequencies for each of the surveys are given in Appendix 1.

The biomass estimates (when calculated from the length frequency data and percentage sampled) and the scaled length frequency figures were sensitive to the length-weight relationship used (Table 16). For most surveys length-weight data were not available, and so the most appropriate length-weight relationship for that area and season had to be determined. To do this, biomass was calculated from recent surveys in each area using firstly the recorded catch weights and secondly the length frequency data, the percent sampled and various length-weight relationships. The length-weight relationship which gave the estimate of biomass closest to that calculated using recorded catch weight was then used for that series of surveys. The coefficients used for each survey are shown in Appendix 1.

The estimates of total biomass and *c.v.*s for each survey are given in Table 17. The biomass estimates are similar to those presented by Annala & Sullivan (1997), except for two surveys in the Hauraki Gulf where some stations caught red gurnard for which no catch or length-frequency data were available. The *c.v.*s are reasonably low in most surveys, indicating that the trawl surveys may be a good technique for monitoring red gurnard abundance. Although there is quite marked between-year variation, the biomass estimates have shown no strong upward or downward trends over time. The only area where there appears to have been a decline is QMA 8. However, because of the high *c.v.* in the 1996 survey, the decline is not significant. Biomass estimates in the Hauraki Gulf appear to be lower since 1988, but this may be due to the change in net parameters outlined above. Francis *et al.* (1995) noted that there had been a greater catchability of juvenile snapper since 1988, which they considered was due to changes in fishing gear.

5.2 Length composition

The scaled length frequency distributions are similar for each of the areas (Figures 5–8). Males typically ranged from 20 to 35 cm, with a single mode at about 25 cm. Females ranged from 20 to 40 cm, with a less pronounced mode at about 27–28 cm. Occasionally a mode of smaller (1 year old) fish with a peak at about 15 cm is present. The greater proportion of longer fish caught during the east coast North Island survey was probably due to the larger mesh size used.

5.3 Age composition

The scaled numbers at age from the trawl surveys are shown in Figures 9 and 10. The age compositions from all four surveys are very similar. The male age distribution is dominated by 2 year old fish in all four surveys, whereas the female age distribution comprises older fish ranging from age 2 to 6. Few fish caught were older than age 8, and no particularly strong year classes are evident. Elder (1976) recorded a similar situation for red gurnard from the Hauraki Gulf, with the male distribution dominated by 2 year olds, but the female distribution by 3 year olds. He concluded that red gurnard females recruited to the trawl grounds a year later than males.

5.4 Estimation of 1 year old biomass from all trawl surveys

The trawl survey length frequency data sometimes had a small mode of 1 year old fish present, which may indicate a strong year class (*see* Figures 5–8). Because there was usually some overlap between the modes of 1 and 2 year old fish, it was necessary to define a length below which most of the fish were age 1. The age-length keys described in Section 5.1 were examined for this purpose. With the exception of the west coast North Island survey KAH9410, there were insufficient small fish (i.e., smaller than 20 cm) aged to allow an appropriate length to be determined which could separate the 1 and 2 year old fish. Analysis of the KAH9410 data suggested fish less than 20 cm were predominantly 1 year olds, and fish greater than 20 cm were predominantly 2 years old or greater. Examination of the modes of the KAH9410 length frequency data also suggested the 1 year old mode extended to 19 cm (*see* Figure 6). A length range of 10 to 19 cm was therefore used for all surveys of the west coast North Island except 1991 (KAH9111), where there appeared to be a slow-growing, strong 2 year old year class, and an upper length of 18 cm was used. Examination of length modes for the other areas suggested an upper length of 19 cm for Bay of Plenty surveys (except KAH8711 which was carried out at a different time of year), and an upper length of 18 cm for Hauraki Gulf surveys, except for KAH8716, for which 17 cm was used. The east coast North Island survey used a 100 mm codend and caught very few 1 year old fish, so those data were not analysed further.

Biomass estimates of 1 year old fish are given in Table 17.

6. ESTIMATION OF BIOLOGICAL PARAMETERS

6.1 Total mortality

Estimates of total mortality (Z) were made using catch curve analysis, which assumes (amongst other things) that the trawl survey representatively samples all ages of the red gurnard population (after a given age), and that recruitment has been constant over time. It is unlikely that adult gurnard swim fast enough to avoid capture by the trawl, and there are no known migrations of larger red gurnard out of the survey areas, so it is likely that the trawl survey age distribution reflects the adult population structure. However, it is unlikely that recruitment is constant over time, indeed the trawl survey data suggest that the number of 1 year olds varies substantially between years (*see* Table 17). Systematic changes in recruitment over time, or the occurrence of one or two strong year classes at the beginning of the time series, could result in large biases in total mortality estimates. Because of the uncertainty underlying the assumptions, the results should be interpreted with caution. They are therefore presented here as ancillary information rather than for use in the modelling.

Estimates of total mortality for the Hauraki Gulf are 0.75 for males and 0.63 for females (Figure 11). Elder (1976) obtained similar estimates of 0.60 and 0.65 respectively. Estimates of total mortality for the west coast North Island are 0.80 for males and 0.51 for females (Figure 11).

6.2 Natural mortality

Estimates of instantaneous natural mortality (M) were calculated for male and female fish using the following equation:

$$M = -\frac{\log_e(p)}{A}$$

where p is the proportion of the population that reaches age A (or older) in an unexploited stock (Annala *et al.* 1998). Although none of the stocks could be considered to be unexploited (even back in 1976), they do not appear to have been heavily exploited. Therefore, A was set to the maximum ages observed and p was set to 0.01.

Elder (1976) obtained a maximum age of 15 years (sex unspecified) during his study of the Hauraki Gulf. During the present study maximum ages of 9 and 13 were recorded for males and females respectively in the Hauraki Gulf, and maximum ages of 13 for males and females on the west coast North Island. There is no reason to suspect natural mortality is different between areas, but the age distribution data suggest that males have a higher natural mortality than females. Assuming a maximum age of 13 years for males and 15 years for females results in estimates of natural mortality of 0.35 and 0.30 for males and females respectively. These estimates were applied to all areas.

6.3 Trawl survey vulnerability, maturity, and selectivity ogives

Trawl survey vulnerability, maturity, and fishing selectivity ogives are required as input parameters for the MIAEL modelling. Both Elder's (1976) results and those of the present study show that males have recruited to the trawling grounds by age 2 and females have recruited by age 3. It is therefore assumed that males are fully vulnerable to trawl gear by age 2 and females by age 3. By comparing the proportion of 1 and 2 year old females and 1 year old males relative to the number of 2 year old males, the vulnerability of those age classes to the trawl survey can be estimated (Tables 18–20).

Elder (1976) examined the age at maturity of red gurnard in the Hauraki Gulf. One year old fish were all immature and 3 year old fish were all mature. Of fish of both sexes on the offshore trawling grounds, 80% were mature at age 2, whereas less than 50% of fish inshore were mature. The maturity state of the 2 year old females before they recruit to the grounds is not known, but it is likely that they are still immature. Therefore for the modelling it has been assumed that 75% of males mature at age 2, and that 25% of females mature at age 2 (i.e., 75% of the fish on the grounds) (Table 18). The same maturity ogives have been assumed for the west coast and east coast fish (Tables 19 and 20).

Although 2 and 3 year old fish are available on the trawling grounds, they are not fully selected by the commercial trawl fishery. Massey (1988) carried out gear selectivity studies on red gurnard and showed that a 100 mm mesh codend retained 10%, 50%, and 90% of fish of 18 cm, 25.7 cm, and 33 cm lengths respectively. Based on the mean length at age the corresponding gear selectivity ogive was calculated for each area (Tables 18–20).

7. MODELLING

7.1 MIAEL model and input parameters

The MIAEL model was used to estimate biomass and yield (MCY) following the methodology given by Cordue (1993, 1996). For the stock assessment it has been assumed that GUR 1E, GUR 1W, and GUR 2 are separate stocks. It is not known whether this is the case but given their limited swimming ability it is likely that there is little mixing between these areas. The catch history used for modelling was based on the commercial landings of red gurnard given in Table 1, and did not include any estimates of recreational catch. The catch was assumed to have been taken throughout the year from the home ground according to the Baranov catch equation and the fishing selectivity patterns given in Tables 18–20. An instantaneous spawning season with a zero catch was assumed at the end of the fishing year. Estimates of B_{min} and B_{max} were obtained assuming r_{max} of 0.5 (with a sensitivity at 0.3), and r_{mmx} (minimum exploitation rate in the year with the maximum catch) of 0.01 (Table 21). Other model parameters assumed for the base case and sensitivity analyses for each of the three stocks are shown in Table 21.

A summary of the biological parameters for red gurnard by stock is shown in Table 22. Estimates of *M* and von Bertalanffy growth parameters are from the present study. Estimates of the length-weight coefficients for GUR 1E and GUR 1W are from the Bay of Plenty trawl survey (KAH8303), and estimates for GUR 2 are from the west coast South Island survey (KAH9701). Estimates of the various trawl survey vulnerability, maturity and fishing selectivity ogives are given in Tables 18–20.

7.2 Abundance indices and proportion-at-age data

A summary of years for which abundance indices and proportion-at-age are available by stock is given in Table 23. CPUE and adult trawl survey indices are available for each stock, and estimates of proportion-at-age are available from two trawl surveys for each of GUR 1W and GUR 1E. The CPUE indices were derived from bycatch fisheries and there is some doubt as to how well these might index abundance. Therefore, catch per unit effort indices derived using the log-linear model were used only in sensitivity analyses, and were given a lower weighting than the trawl surveys.

The Working Group considered that the 1985 surveys of the Bay of Plenty and Hauraki Gulf were anomalous because biomass estimates were extremely low for a number of species: they were therefore excluded from the modelling. They also agreed to exclude the Bay of Plenty 1987 survey from the modelling because it was carried out at a different time of year, and to treat the Hauraki Gulf trawl surveys as a single series. Estimates of recruitment (i.e., numbers of 1+ year class fish) and proportion-at-age data were available from a number of trawl surveys. There was concern over how well these data represented the population, so they were initially not used in the modelling work. However, to evaluate their usefulness, they were later incorporated into separate model runs for GUR 1E and GUR 1W.

7.3 Model results

GUR 1W

The MIAEL estimate of B_0 for GUR 1W is about 15 900 t, with a low performance index of 11% (Table 24). The estimate is not particularly sensitive to changes in the input parameters, but the performance index dropped to 4% when r_{max} was changed to 0.3. The MIAEL estimate of B_{mid99} is about 70% of B_0 (Figure 12), and has a much higher performance index of almost 60%. The estimate is not particularly sensitive to changes in the input parameters, however, the performance index dropped to only 12% when r_{max} was changed to 0.3. This suggests that the higher performance index was a result of the assumed value of r_{max} which is not well known.

The assessment for GUR 1W suggests that the stock has been only lightly exploited. Even if the stock were at B_{min}, the current biomass would still be greater than 35% B_0, and the current level of catches would be sustainable, as indicated by the increasing stock trajectory (Figure 12). Results of the catch curve analysis (Section 7.1) implied instantaneous fishing mortality rates of 0.3, or catch to biomass ratios of about 0.2, for the early 1990s. These estimates suggest a stock at B_{min}, so are not consistent with the MIAEL estimate of current biomass.

The fit to the trawl survey index of abundance is shown in Figure 13. The model fitted the trawl survey observations reasonably well, with a catchability coefficient (q) of 0.11. The trawl survey index is also consistent with the trend in CPUE, which suggests no change in gurnard abundance since 1989–90. Based on the value for q, the fit to the indices, and the agreement with the CPUE data, it appears that the trawl survey series is providing a useful index of abundance for this stock. The poorer fit to the 1989 and 1994 surveys possibly reflect true short-term changes in the population that cannot be modelled assuming deterministic recruitment.

The incorporation of proportion at age data and estimates of 1+ year class strengths from the trawl survey enabled the estimation of year class strengths from 1985 to 1995 (Table 25). The biomass trajectories (Figure 14) demonstrate the effect of several years of above average recruitment in the 1990s. The MIAEL estimate of B_0 is markedly higher than in the base case and other sensitivity runs, but the performance index and the bounds around B_0 are essentially unchanged (Table 24). The model fit to the trawl survey indices appears to have improved (the 1989 and 1994 data points no longer seem anomalous), and the fits to the estimates of 1+ year class strength and the proportion-at-age data are generally good (Figure 15). Although the q for the trawl survey (0.007) is unrealistic in this model run, this reflects the high least squares estimate which was at the upper bound. The least squares estimates of virgin and current biomass are both at the upper end of the bounds for these parameters, and are therefore dependent on r_{max}. The estimate of current biomass has a very low performance index (3%), which is unexpected given the much wider bounds around this parameter. Stochastic recruitment allows the biomass to increase to levels greater than B_0, and this has occurred here. The MIAEL estimate of current biomass still indicates that the stock has been only lightly exploited.

GUR 1E

The base case estimate of B_0 for GUR 1E is about 12 800 t, but this is very poorly known as it has a performance index of only 1% (*see* Table 24). The estimate is quite sensitive to changes in the input parameters. The estimate of B_{mid99} is about 27% of B_0, but this is also very poorly known as it has a performance index of less than 1% (*see* Table 24). The estimate of B_{mid99} is sensitive to changes in the input parameters, in particular to the value used for r_{max}, and ranged from 26 to 53% of B_0.

The low performance indices were initially surprising because of the relatively large number of abundance indices being fitted in the model. However, all the abundance indices monitor the period after the most intense fishing pressure, and during that time the trajectories for B_{min} and B_{max} are both very flat (*see* Figure 12). Results of the catch curve analysis (Section 7.1) implied catch to biomass ratios of about 0.2 and 0.25, for the late 1960s and early 1990s respectively. These estimates are similar to those calculated if the stock were at B_{min}.

The fits to the trawl survey indices of abundance are shown in Figure 13. The model fitted the Bay of Plenty trawl survey index reasonably well, but had a very low q of 0.004. However, this reflects the high least squares estimate which was at the upper bound. The model appears unable to fit the decline observed in the early years of the Hauraki Gulf survey, and essentially fits a straight line. Again, the trawl survey index had a very low q of only 0.003. Although the two trawl surveys do not cover the whole area of GUR 1E, and part of the gurnard stock may be in shallow water or in non-trawlable areas, a combined q of less than 0.01 appears unrealistic, particularly when compared to the q estimates from the other two areas.

The low performance index and poor fit to the abundance indices suggest an extremely high level of uncertainty in this assessment. One reason for this uncertainty may be the assumption of deterministic recruitment in the model.

Incorporation of proportion-at-age data and estimates of 1+ year class strengths from the trawl surveys enabled the estimation of year class strengths from 1984 to 1997 (*see* Table 25). The biomass trajectories for this model run are presented in Figure 14. The MIAEL estimate of B_0 is markedly higher than in the base case and other sensitivity runs, and the performance index and B_{max} bound have also increased (*see* Table 24). However, the reliability of this assessment, based on the performance indices, is still very low. The model fit to the Hauraki Gulf trawl survey indices have improved markedly (only the 1988 point is now anomalous), and the fits to the estimates of 1+ year class strength are also good (with the exception of in 1984) (Figure 16). Fits to the proportion-at-age data are reasonable (Figure 16). Model fits to the data from the Bay of Plenty trawl surveys are very good since 1992, but exhibit some variance in the two prior surveys (Figure 17). [Note: The data from the 1999 survey was available only for the model run incorporating the age data, and not for the base case and other sensitivity runs, which were completed in 1998.] The q values for both trawl survey series are realistic in this model run (i.e., 0.11 and 0.17). The estimate of current biomass has a performance index markedly superior to the base case run (*see* Table 24). The MIAEL estimate of current biomass is the highest of all the model runs and indicates that the stock has probably not been heavily exploited.

GUR 2

The estimate of B_0 for GUR 2 is about 11 900 t, but this is very poorly known as it has a performance index of less than 1% (*see* Table 24). The estimate is not particularly sensitive to changes in the input parameters. The estimate of B_{mid99} is about 34% of B_0, but this is also very poorly known as it has a performance index of only 1% (*see* Table 24). The estimate of B_{mid99} is reasonably sensitive to changes in the input parameters, in particular to the value used for r_{max}, and ranged from 29 to 59% of B_0. The low performance indices are probably caused by the short and erratic trawl survey time series. Model runs incorporating the CPUE data have better performance indices owing to the CPUE being a longer and more consistent series, but the assessment is still highly uncertain.

The fit to the trawl survey index of abundance is shown in Figure 13. The model fitted the trawl survey observations essentially as a straight line, with a q of 0.31. The trawl survey was also consistent with the trend in CPUE, which suggests a slight decline in gurnard abundance since 1990. Although the value for q, the fit to the indices, and the agreement with the CPUE data all seem reasonable, the trawl survey series is very noisy and regular surveys would be required to monitor the stock because of its poor precision. The actual *c.v.*s from the survey range from 16 to 44%.

7.4 Yield estimates

The method used to estimate MCY was MCY = p.B_0, where p is determined by the method of Francis (1992). Estimates of MCY (Table 26) are much larger than previous values based on average catch (Annala *et al.* 1998). Base case estimates are 2710 t for GUR 1 (GUR 1W and GUR 1E combined) and 1070 t for GUR 2 (compared to the average catch values of 1120 t and 450 t, respectively). When the available age data were incorporated into the assessment for GUR 1, the MCY was estimated to be 5970 t. However, all the estimates of MCY have low performance indices and were also sensitive to the assumed parameter estimates. For all three areas, the reported landings have never exceeded the MCY estimates. In this respect, the new higher MCY estimates for GUR 1E and GUR 2 are inconsistent with the low estimates of current biomass.

7.5 Relationship between year class strengths and commercial catch

The estimates of year class strength (Table 25) cover a reasonably broad range (0.01–3.13). As red gurnard have a relatively short life span and are primarily a bycatch species, it might be expected that levels of commercial catch would fluctuate in conjunction with year class strengths. Gurnard strongly recruit to the commercial fishery at age 3 (*see* Table 18), so it was assumed that the 3+ and 4+ year classes are likely to constitute a significant component of the catch in any year, particularly when one or both of these year classes are strong. To test the relationship between year class strength and landings levels, the mean year class strength of 3+ and 4+ fish in each fishing year was plotted against landings from that year (*see* Figure 18). There is certainly no apparent trend of increasing catches with higher values of mean year class strength.

There are factors which could hide a true relationship between these variables. The total landed weight of fish age 5+ and older may often be sufficient to blur the effect of any particularly strong or weak 3+ and 4+ grouping. Also, the current estimates of year class strength may not be particularly well estimated. At best, a single estimate is based on information from three sets of data, but some are based only on the trawl survey estimate of 1+ fish abundance (*see* Table 17). There are some notable differences in year class strengths between the GUR 1E and GUR 1W stocks (e.g., compare those from 1987, 1992, 1994, and 1995, *in* Table 25), and although recruitment success could vary between the east and west coasts of the North Island, extremes are probably unrealistic.

8. MANAGEMENT IMPLICATIONS

This is the first assessment of red gurnard using a population model. The estimates of virgin and current biomass for all stocks are uncertain, having low performance indices and, in some cases, unrealistic q values or poor fits to the abundance indices. Incorporation of proportion-at-age data and estimates of 1+ recruitment from the trawl surveys in GUR 1 did improve the assessments (particularly for GUR 1E) by allowing a better fit to the abundance indices. It appears likely that a continuation of these trawl survey series (including the associated proportion-at-age data) will improve future assessments. However, the current assessments must still be considered to be very uncertain. Furthermore, the assessments do not include a recreational catch component which would add a further 10–20% to the catch history from each area.

GUR 1W

The assessment for the GUR 1W stock is reasonably optimistic. Both trawl and CPUE indices are increasing, and the model indicated that B_{mid99} was about 80% of B_0 (range 40–147%, performance index 3%), suggesting that the stock has been only lightly exploited and is also benefiting from several recent years of strong recruitment. Current biomass appears to be greater than the size that will support the B_{MSY}. Current catch levels appear to be sustainable, and continued catches at the current level will allow the stock to remain above B_{MSY}.

GUR 1E

The abundance indices all suggest that the biomass in GUR 1E declined in the early 1980s, but recovered slightly during the 1990s. Current biomass appears to be above B_{MSY} (Bmid99 was estimated at 59% of B_0 (range 9–83%, performance index 58%) and current catch levels are probably sustainable. Continued catches at the current level will allow the stock to remain above B_{MSY}.

GUR 2

The very low performance indices and noisy abundance indices suggest a high level of uncertainty in this assessment. Because of this, the assessment for GUR 2 was rejected by the Working Group and was not considered further for management.

9. ACKNOWLEDGMENTS

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Table 1: Reported landings (t) of red gurnard by Fishstock and area for GUR 1 and GUR 2 for the period 1931 to 1997–98, and actual TACs (t) for the period 1986–87 to 1996–97

Year	GUR 1 West	GUR 1 East	GUR 1 Total	GUR 1 TAC	GUR 2 Total	GUR 2 TAC
1931	–	66	66	–	–	–
1932	–	41	41	–	–	–
1933	–	66	66	–	84	–
1934	–	50	50	–	179	–
1935	–	74	74	–	147	–
1936	–	113	113	–	220	–
1937	–	203	203	–	197	–
1938	–	107	107	–	126	–
1939	–	118	118	–	156	–
1940	–	122	122	–	226	–
1941	–	105	105	–	205	–
1942	–	121	121	–	338	–
1943	–	125	125	–	247	–
1944	–	232	232	–	298	–
1945	–	353	353	–	344	–
1946	–	418	418	–	399	–
1947	–	368	368	–	313	–
1948	–	222	222	–	253	–
1949	–	362	362	–	275	–
1950	–	298	298	–	198	–
1951	–	211	211	–	244	–
1952	8	376	384	–	392	–
1953	83	392	475	–	518	–
1954	106	371	478	–	487	–
1955	126	354	480	–	297	–
1956	178	244	422	–	332	–
1957	182	294	476	–	422	–
1958	117	301	418	–	410	–
1959	109	335	444	–	339	–
1960	203	267	469	–	567	–
1961	261	278	539	–	439	–
1962	207	279	486	–	612	–
1963	238	303	541	–	598	–
1964	320	627	947	–	853	–
1965	508	750	1 258	–	706	–
1966	561	557	1 118	–	793	–
1967	549	455	1 004	–	881	–
1968	651	443	1 093	–	611	–
1969	794	502	1 296	–	661	–
1970	832	581	1 413	–	867	–
1971	670	468	1 138	–	602	–
1972	340	401	741	–	368	–
1973	677	577	1 253	–	431	–
1974	512	355	867	–	315	–
1975	386	294	679	–	213	–
1976	610	427	1 037	–	234	–
1977	690	569	1 258	–	400	–
1978	833	696	1 529	–	547	–
1979	1 119	767	1 886	–	407	–
1980	1 153	664	1 817	–	469	–

Table 1 continued

Year	GUR 1 West	GUR 1 East	GUR 1 Total	GUR 1 TAC	GUR 2 Total	GUR 2 TAC
1981	1 499	810	2 308	–	631	–
1982	1 021	987	2 007	–	472	–
1983	629	1 139	1 768	–	344	–
1984	624	1 029	1 653	–	443	–
1984–85	612	919	1 531	–	665	–
1985–86	704	1 056	1 760	–	495	–
1986–87	408	613	1 021	2 010	592	610
1987–88	456	683	1 139	2 081	596	657
1988–89	416	623	1 039	2 198	536	698
1989–90	366	550	916	2 283	451	720
1990–91	449	674	1 123	2 284	490	723
1991–92	518	776	1 294	2 284	663	723
1992–93	652	977	1 629	2 284	618	725
1993–94	461	692	1 153	2 284	635	725
1994–95	422	632	1 054	2 287	559	725
1995–96	465	698	1 163	2 287	567	725
1996–97	422	633	1 055	2 287	503	725
1997–98	406	609	1 015	2 287	482	725

Data sources:
Landings to 1973 from Annual Reports on Fisheries.
Landings 1974 to 1982 from King (1985).
Landings 1983 from King (1986).
Landings of GUR 1 for 1984–85 to 1997–98 from Annala *et al.* (1998). Subdivision into East and West is standardised at the ratio 60:40. This is based on:
(1) Unpublished FSU statistics for 1984 to 1987 which have a ratio by port of 63:37 and by area of 60:40, and
(2) CELR + TCEPR estimated landings for 1990 to 1996 (82% of actual landings) which have a ratio of 62:38.

Table 2: Proportion of total reported gurnard catch 1989–1997 by target species within each area. Species in italics were included in the CPUE analysis

GUR 1E		GUR 1W		GUR 2	
Target	% catch	Target	% catch	Target	% catch
SNA	*19*	*SNA*	*27*	*GUR*	*15*
TAR	*15*	*TRE*	*24*	*TAR*	*15*
JDO	*14*	*TAR*	*17*	*TRE*	*12*
GUR	*13*	*GUR*	*15*	*SNA*	*10*
TRE	*13*	BAR	8	BAR	10
BAR	10	SWA	5	FLA	10
FLA	7	JDO	4	WAR	8
LEA	3			HOK	7
RCO	3			SKI	6
SKI	3			JDO	5
				RCO	3

Table 3: Statistical areas included in the gurnard CPUE analysis

	Areas included	Areas excluded
GUR 1E	002, 003, 004, 005, 006, 008, 009, 010	Firth of Thames (007) offshore areas
GUR 1W	042, 045, 046, 047	Manakau Harbour (043) Kaipara Harbour (044) offshore areas
GUR 2	011, 012, 013, 014, 015, 016	offshore areas

Table 4: Summary of variables offered to the models for CPUE standardisation. Variable types are: cont, continuous; cat, categorical with the given number of categories

Variable	Type	Description
Year	cat 8	fishing year (1 October – 30 September)
Month	cat 12	month of fishing
Area	cat 8 (GUR 1E) cat 4 (GUR 1W) cat 6 (GUR 2)	statistical area that the fishing took place in
Target species	cat 5 (GUR 1E) cat 4 (GUR 1W) cat 4 (GUR 2)	target species reported with catch and effort data
Area*target	cat 40 (GUR 1E) cat 16 (GUR 1W) cat 24 (GUR 2)	area-target interaction effect
Vessel draught	cont	vessel draught in metres
Vessel breadth	cont	vessel breadth in metres
Vessel power	cont	power of vessel engine in kilowatts
Vessel tonnage	cont	gross tonnage of the vessel
Year vessel built	cont	year the vessel was reported built

Table 5: Summary of CELR and TCEPR catch and effort data and raw CPUE (kg/day) for gurnard in the target gurnard, snapper, tarakihi, and trevally fisheries in GUR 1W

Fishing year	Catch (t)	Days fished	Days with zero catch	Proportion days zero	Raw CPUE (kg/day)
1989–90	128	829	259	0.31	154.5
1990–91	155	954	228	0.24	162.5
1991–92	209	1 103	264	0.24	189.6
1992–93	462	1 669	336	0.20	276.6
1993–94	338	1 520	389	0.26	222.2
1994–95	350	1 295	336	0.26	270.4
1995–96	359	1 594	445	0.28	225.0
1996–97	351	1 815	556	0.31	193.4

Table 6: Comparison of variables selected in the GUR 1W regression models in the order in which they entered the model down to 1% improvement in the model or until fishing years was included

	Linear model		Binomial model	
Iteration	Variable	(% improve)	Variable	(% improve)
1	target	–	target	–
2	fishing year	(2.15)	month	(2.00)
3	month	(1.15)	v. year built	(2.25)
4	v. year built	(1.41)	area	(1.00)
5			area*target	(0.83)
5			v. draught	(0.96)
6			v. breadth	(0.26)
7			fishing year	(0.36)

Table 7: Relative year effects from the linear model of log(catch per day), binomial model of successful days (catch greater than zero) and unsuccessful days (zero catch) fishing, and combined indices for GUR 1W

Year	Linear	Binomial	Combined
1989–90	1.00	1.00	1.00
1990–91	0.90	0.87	0.94
1991–92	0.97	0.97	0.98
1992–93	1.35	0.64	1.52
1993–94	1.20	0.87	1.25
1994–95	1.46	0.82	1.55
1995–96	1.20	0.87	1.25
1996–97	1.04	1.06	1.02

Table 8: Summary of CELR and TCEPR catch and effort data and raw CPUE (kg/day) for gurnard in the target gurnard, snapper, tarakihi, trevally, and john dory fisheries in GUR 1E

Fishing year	Catch (t)	Days fished	Days with zero catch	Proportion days zero	Raw CPUE (kg/day)
1989–90	154	3 156	1 258	0.40	48.8
1990–91	190	4 231	1 618	0.38	45.0
1991–92	246	4 878	1 712	0.35	50.4
1992–93	174	3 726	1 370	0.37	46.8
1993–94	115	3 773	1 712	0.45	30.4
1994–95	71	3 199	1 780	0.56	22.1
1995–96	66	3 474	2 055	0.59	19.1
1996–97	71	3 676	2 202	0.60	19.4

Table 9: Comparison of variables selected in the GUR 1E regression models in the order in which they entered the model down to 1% improvement in the model

	Linear model		Binomial model	
Iteration	Variable	(% improve)	Variable	(% improve)
1	area	–	target	–
2	fishing year	(5.86)	fishing year	(3.03)
3	month	(2.95)	v. year built	(2.66)
4	v. year built	(2.64)	area	(1.88)
5	target	(2.71)	v. draught	(1.67)
6	area*target	(2.06)	month	(1.46)
7	v. draught	(1.72)		

Table 10: Relative year effects from the linear model of log(catch per day), binomial model of successful days (catch greater than zero) and unsuccessful days (zero catch) fishing, and combined indices for GUR 1E

Year	Linear	Binomial	Combined
1989–90	1.00	1.00	1.00
1990–91	0.90	0.98	0.91
1991–92	0.85	0.86	0.90
1992–93	0.81	0.98	0.82
1993–94	0.64	1.58	0.52
1994–95	0.62	2.18	0.42
1995–96	0.50	2.57	0.31
1996–97	0.43	3.34	0.22

Table 11: Summary of CELR and TCEPR catch and effort data and raw CPUE (kg/day) for gurnard in the target gurnard, snapper, tarakihi, and trevally fisheries in GUR 2

Fishing year	Catch (t)	Days fished	Days with zero catch	Proportion days zero	Raw CPUE (kg/day)
1989–90	287	2 114	778	0.37	135.6
1990–91	394	2 852	960	0.34	138.2
1991–92	511	3 379	860	0.25	151.1
1992–93	473	3 137	816	0.26	150.7
1993–94	477	3 477	914	0.26	134.6
1994–95	357	3 148	1 048	0.33	113.4
1995–96	316	2 562	849	0.33	123.5
1996–97	285	2 452	780	0.32	116.2

Table 12: Comparison of variables selected in the GUR 2 regression models in the order in which they entered the model down to 1% improvement in the model

	Linear model		Binomial model	
Iteration	Variable	(% improve)	Variable	(% improve)
1	target	–	target	–
2	v. gross tonnage	(4.17)	area	(7.59)
3	month	(1.27)	v. draught	(0.69)
4	v. year built	(1.30)	month	(0.54)
5	area	(1.21)	fishing year	(0.55)
6	fishing year	(0.76)		

Table 13: Relative year effects from the linear model of log(catch per day), binomial model of successful days (catch greater than zero) and unsuccessful days (zero catch) fishing, and combined indices for GUR 2

Year	Linear	Binomial	Combined
1989–90	1.00	1.00	1.00
1990–91	0.93	0.85	0.98
1991–92	0.91	0.64	1.05
1992–93	0.88	0.76	0.97
1993–94	0.80	0.84	0.85
1994–95	0.76	1.09	0.74
1995–96	0.83	1.07	0.81
1996–97	0.73	1.09	0.71

Table 14: Number of otoliths read by area, year, and sex

Survey	Area	Date	Male	Female	Total
KAH9212	Hauraki Gulf	Nov 1992	51	62	113
KAH9410	west coast NI	Oct 1994	99	119	218
KAH9411	Hauraki Gulf	Oct 1994	65	75	140
KAH9601	Bay of Plenty	Feb 1996	32	37	69
KAH9615	west coast NI	Oct-Nov 1996	93	122	215

Table 15: Von Bertalanffy growth parameters (1 standard error) for red gurnard from the west coast North Island and Hauraki Gulf

	n	Age range	L_∞	K	t_0
Hauraki Gulf					
Males	119	1–9	35.21 (1.28)	0.49 (0.08)	–0.24 (0.24)
Females	142	1–13	44.96 (1.63)	0.28 (0.04)	–0.76 (0.27)
Combined sexes	261	1–13	43.48 (1.33)	0.29 (0.03)	–0.64 (0.18)
West Coast North Island					
Males	212	1–13	36.49 (0.79)	0.45 (0.04)	–0.30 (0.14)
Females	262	1–13	45.27 (1.29)	0.25 (0.03)	–0.88 (0.20)
Combined sexes	474	1–13	43.96 (1.04)	0.25 (0.02)	–1.02 (0.18)

Table 16: Comparison of biomass estimates calculated from catch weights, with those calculated from length frequency data using alternative length weight relationships

	Catch weights		KAH8303		KAH9502		KAH9205	
	Biomass (t)	*c.v.*%	Biomass (t)	*c.v.*%	Biomass (t)	*c.v.*%	Biomass (t)	*c.v.*%
Bay of Plenty								
KAH9004	413.0	11.3	432.3	11.9	385.7	11.8	316.9	11.6
KAH9202	271.1	9.5	289.5	9.5	261.3	9.5	217.1	9.5
KAH9601	321.2	14.1	332.1	13.7	298.7	13.7	247.4	13.6
West coast North Island (FMA 9)								
KAH9111	1 845.8	22.5	1 903.6	22.1	1 679.8	21.9	1 339.2	21.9
KAH9410	2 497.6	29.6	2 596.3	30.2	2 313.7	30.1	1 893.9	30.6
KAH9615	1 819.6	14.1	2 040.6	13.9	1 805.0	13.8	1 458.1	13.6
Hauraki Gulf								
KAH9212	330.4	8.8	340.0	8.5	306.3	8.5	258.1	8.6
KAH9311	176.6	16.6	187.7	16.3	169.5	16.3	140.9	16.5
KAH9411	246.6	19.1	245.8	18.8	219.7	18.7	181.0	18.6

Table 17: Estimates of red gurnard biomass (t) from Kaharoa trawl surveys. – not calculated

		Total		1yr old fish		2yr old or greater	
Year	Trip code	Biomass	*c.v.*%	Biomass	*c.v.*%	Biomass	*c.v.*%
Bay of Plenty							
1983#	KAH8303	380	23	8.8	23	371	23
1985#	KAH8506	57	17	0.2	52	56	17
1987#‡	KAH8711	410	28	–	–	–	–
1990#	KAH9004	432	12	15.2	34	417	12
1992#	KAH9202	271	10	1.4	25	270	10
1996#	KAH9601	331	14	3.4	32	328	14
1999	KAH9902	367	14	1.7	41	365	14
West coast North Island (FMA 9)							
1986	KAH8612	1 763	16	45.2	26	1 718	16
1987#	KAH8715	2 022	24	35.9	25	1 986	25
1989	KAH8918	1 013	12	10.4	25	1 003	12
1991	KAH9111	1 846	23	11.2	42	1 835	22
1994	KAH9410	2 498	30	42.8	30	2 455	30
1996	KAH9615	1 820	14	73.3	21	1 746	14
West coast North Island (FMA 8)							
1989	KAH8918	628	15	8.7	39	620	15
1991	KAH9111	817	9	6.0	52	811	9
1994	KAH9410	685	22	3.2	47	681	22
1996	KAH9615	370	37	2.9	44	367	38
Hauraki Gulf							
1984#	KAH8421	*595	15	5.7	37	589	15
1985#	KAH8517	49	44	0.1	62	49	44
1986#	KAH8613	426	36	0.4	57	426	36
1987#	KAH8716	255	15	0.3	51	254	15
1988#	KAH8810	749	19	0.7	25	748	19
1989	KAH8917	105	29	0.2	49	105	29
1990	KAH9016	141	16	0.4	38	141	16
1992	KAH9212	330	9	1.0	26	329	9
1993	KAH9311	177	17	0.1	71	176	17
1994	KAH9411	247	19	3.4	19	243	19
1997	KAH9720	242	14	2.1	20	240	14
East coast North Island							
1993	KAH9304	439	44	–	–	–	–
1994	KAH9402	871	16	–	–	–	–
1995	KAH9502	178	26	–	–	–	–
1996	KAH9605	708	29	–	–	–	–

Calculated from length frequency data

‡ Survey conducted in May-June, other Bay of Plenty surveys carried out in Feb-Mar

* Excludes stations where no catch or length frequency data available

Table 18: Trawl survey vulnerability (TSV), maturity, and fishing selectivity ogives for male and female red gurnard in the Hauraki Gulf

	Males			Females		
Age	TSV	Maturity ogive	Fishing selectivity	TSV	Maturity ogive	Fishing selectivity
1	0.1	0	0.1	0.1	0	0.1
2	1	0.75	0.35	0.3	0.25	0.35
3	1	1	0.6	1	1	0.7
4	1	1	0.8	1	1	1
5	1	1	0.9	1	1	1
≥6	1	1	1	1	1	1

Table 19: Trawl survey vulnerability (TSV), maturity, and fishing selectivity ogives for male and female red gurnard from the west coast North Island

	Males			Females		
Age	TSV	Maturity ogive	Fishing selectivity	TSV	Maturity ogive	Fishing selectivity
1	0.25	0	0.1	0.1	0	0.1
2	1	0.75	0.35	0.4	0.25	0.35
3	1	1	0.6	1	1	0.65
4	1	1	0.8	1	1	0.85
5	1	1	0.9	1	1	1
≥6	1	1	1	1	1	1

Table 20: Trawl survey vulnerability (TSV), maturity, and fishing selectivity ogives for male and female red gurnard from the east coast North Island

	Males			Females		
Age	TSV	Maturity ogive	Fishing selectivity	TSV	Maturity ogive	Fishing selectivity
1	0.1	0	0.1	0.1	0	0.1
2	0.35	0.75	0.35	0.35	0.25	0.35
3	0.6	1	0.6	0.7	1	0.7
4	0.8	1	0.8	1	1	1
5	0.9	1	0.9	1	1	1
≥6	1	1	1	1	1	1

Table 21: Input parameters for the MIAEL modelling

Parameter	Estimate	Sensitivity
Steepness	0.9	–
Recruitment variability	0.6	–
Natural mortality males	0.35	±0.05
Natural mortality females	0.3	±0.05
Maximum exploitation (r_{max}) pre-spawning, spawning	0.5	0.3
Minimum exploitation rate when largest catch (r_{mmx})	0.01	–

Table 22: Biological parameters (i.e., natural mortality, von Bertalanffy, and length-weight) for red gurnard, by stock

	GUR 1W		GUR 1E		GUR 2	
	Males	Females	Males	Females	Males	Females
M	0.35	0.30	0.35	0.30	0.35	0.30
L_∞	36.5	45.3	35.2	44.5	35.2	44.5
K	0.45	0.25	0.49	0.28	0.49	0.28
t_0	–0.30	–0.88	–0.24	–0.76	–0.24	–0.76
a	0.026	0.026	0.026	0.026	0.0053	0.0053
b	2.775	2.775	2.775	2.775	3.19	3.19

Table 23: Input data sets available for red gurnard by stock. BoP, Bay of Plenty; HG, Hauraki Gulf. For details of trawl surveys, *see* Table 17. Data in italics only used in sensitivity tests

Data set	GUR 1W	GUR 1E	GUR 2
Trawl survey adult biomass indices	1986–96	BoP 1983–99 (excl. 1985 & 1987) HG 1984–97 (excl. 1985)	1993–96
Trawl survey 1+ indices	1986–96	BoP 1983–99 (excl. 1985 & 1987) HG 1984–97 (excl. 1985)	1993–96
Trawl survey proportion-at-age	1994, 1996	HG 1992, 1994	
CPUE indices	*1990–97*	*1990–97*	*1990–97*

Table 24: Estimates of B_{min} and B_{max}, least squares (LS) estimates of biomass, and MIAEL estimates of *p*, biomass (MIAEL), and performance indices (Perf.), for the base case assessment and sensitivity runs for GUR 1W, GUR 1E, and GUR 2. r_{max}, maximum exploitation rate; cpue, inclusion of cpue index; age data, inclusion of catch-at-age data. Biomass estimates are: mid-spawning season virgin biomass (B_0) in tonnes, and mid-spawning season mature biomass for 1998–99 (B_{mid99}) as a percentage of virgin biomass. All sensitivities tests should be compared to the no age data run

Estimate	Run	B_{min}–B_{max}	LS	*p*	MIAEL	Perf. %
GUR 1W						
B_0	**Base case**	**5 090–101 930**	**101 930**	**0.128**	**27 050**	**9.5**
	No age data	5 020–101 980	15 680	0.131	15 860	10.7
	M +0.05	4 540–93 800	18 310	0.122	14 920	9.8
	M –0.05	5 880–110 420	14 930	0.133	17 790	10.5
	r_{max} = 0.3	6 160–101 900	15 680	0.078	18 190	4.3
	cpue	5 000–101 950	13 060	0.136	15 480	11.3
$B_{mid99(\%B0)}$	**Base case**	**40.0–147.2**	**147.2**	**0.111**	**79.9**	**2.6**
	No age data	36.7–98.0	76.3	0.645	69.7	58.6
	M +0.05	52.7–98.1	80.0	0.473	75.1	36.3
	M –0.05	38.1–97.8	72.9	0.585	67.1	49.5
	r_{max} = 0.3	65.5–98.0	79.7	0.237	79.6	11.5
	cpue	34.6–98.0	74.8	0.681	68.7	64.3
GUR 1E						
B_0	**Base case**	**6 290–94 490**	**94 490**	**0.169**	**31 140**	**13.5**
	No age data	5 000–76 920	76 920	–0.030	12 770	1.0
	M +0.05	4 310–70 680	70 680	–0.034	10 860	1.5
	M –0.05	5 930–83 630	83 630	–0.006	16 460	0.0
	r_{max} = 0.3	5 460–76 920	76 920	0.026	17 180	0.6
	cpue	5 000–76 920	76 920	–0.019	13 460	0.4
$B_{mid99(\%B0)}$	**Base case**	**8.7–82.6**	**82.6**	**0.619**	**59.4**	**58.4**
	No age data	11.2–96.1	96.1	–0.011	26.5	0.0
	M +0.05	10.8–96.4	96.4	–0.037	24.0	1.1
	M –0.05	13.6–95.7	95.7	0.031	32.9	0.5
	r_{max} = 0.3	31.0–96.1	96.1	0.124	57.3	4.1
	cpue	11.2–96.1	96.1	0.003	27.5	0.0
GUR 2						
B_0	**Base case**	**4 080–61 890**	**4 260**	**–0.002**	**11 890**	**0.0**
	M +0.05	3 610–57 030	3 610	–0.008	10 710	0.0
	M –0.05	4 770–66 750	5 000	0.006	13 510	0.0
	r_{max} = 0.3	4 770–61 890	4 770	–0.011	13 350	0.1
	cpue	4 080–61 890	4 260	0.050	11 500	1.9
$B_{mid99(\%B0)}$	**Base case**	**15.8–96.0**	**26.4**	**0.039**	**33.8**	**0.7**
	M +0.05	25.3–96.2	25.3	0.043	45.0	0.7
	M –0.05	12.7–95.6	23.4	0.049	29.2	1.2
	r_{max} = 0.3	39.3–96.0	39.3	0.021	59.0	0.1
	cpue	15.8–96.0	28.2	0.158	33.0	8.1

Table 25: Estimates of year class strengths from model runs incorporating age data. –, not estimated

Year class	GUR 1W	GUR 1E
1984	–	0.01
1985	0.95	0.42
1986	0.85	0.37
1987	0.01	0.82
1988	0.22	0.61
1989	0.72	1.04
1990	0.29	0.13
1991	2.56	1.44
1992	3.13	0.13
1993	0.92	2.45
1994	2.11	0.29
1995	1.59	0.01
1996	–	2.45
1997	–	0.13

Table 26: Estimates of B_{MCY} (as % of B_0), MCY (as %B_0), MCY range (t) (from B_{min} and B_{max}), and MCY (t) (from MIAEL) and its performance index (Perf.), for the base case assessment and sensitivity runs for GUR 1W, GUR 1E, and GUR 2. All sensitivities tests should be compared to the no age data run

Fishstock	Model run	B_{MCY} (% of B_0)	MCY (% of B_0)	MCY Range	MCY (t)	Perf. (%)
GUR 1W	**Base case**	**48.1**	**10.2**	**520–10 400**	**2 760**	**9.5**
	No age data	48.0	9.4	470–9 570	1 490	10.7
	M+0.05	49.5	10.7	480–10 070	1 600	9.8
	M–0.05	46.7	8.1	470–8 910	1 430	10.5
	$r_{max} = 0.3$	47.0	10.3	630–1 040	1 860	4.3
	cpue	48.0	9.4	470–9 580	1 450	11.3
GUR 1E	**Base case**	**48.9**	**10.3**	**650–9 730**	**3 210**	**13.5**
	no age data	48.3	9.6	470–7 360	1 220	1.0
	M+0.05	49.5	10.9	470–7 710	1 180	1.5
	M–0.05	46.7	8.2	480–6 880	1 350	0.0
	$r_{max} = 0.3$	47.1	10.5	570–8 050	1 790	0.6
	cpue	48.3	9.6	470–7 360	1 280	0.4
GUR 2	**Base case**	**48.3**	**9.1**	**370–5 610**	**1 070**	**0.0**
	M+0.05	49.8	10.3	370–5 890	1 100	0.0
	M–0.05	46.7	7.8	370–5 210	1 050	0.0
	$r_{max} = 0.3$	47.0	9.9	470–6 150	1 320	0.1
	cpue	48.3	9.1	370–5 610	1 040	1.9

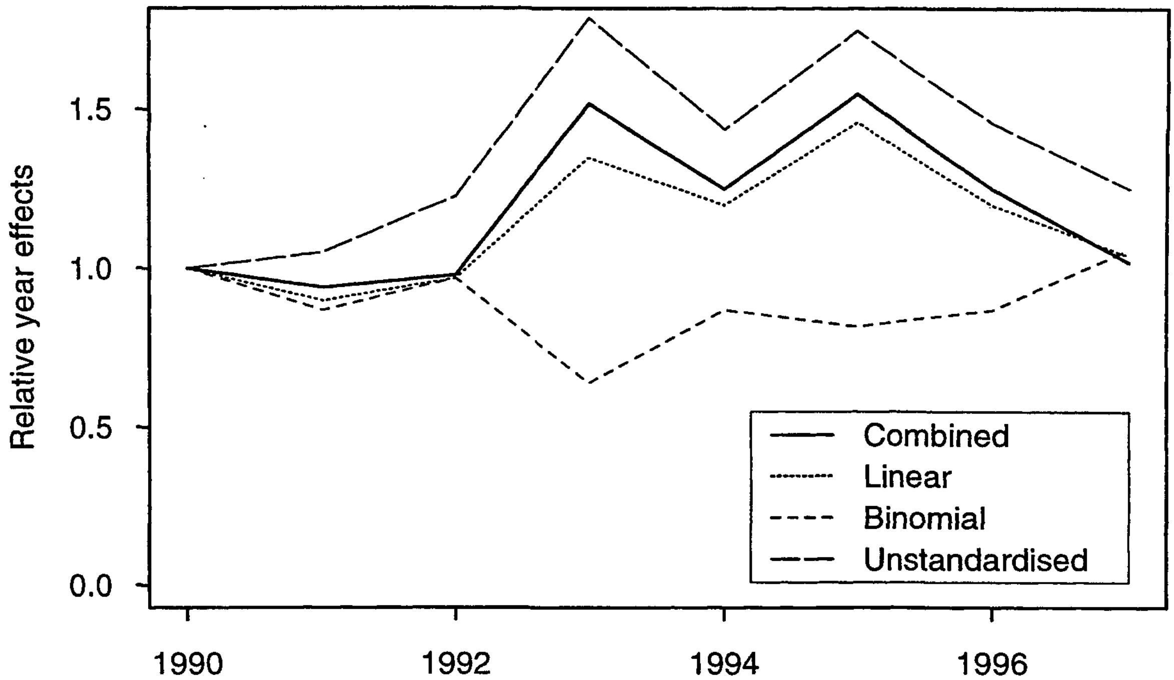

Figure 1: Comparison of relative year effects for GUR 1 West.

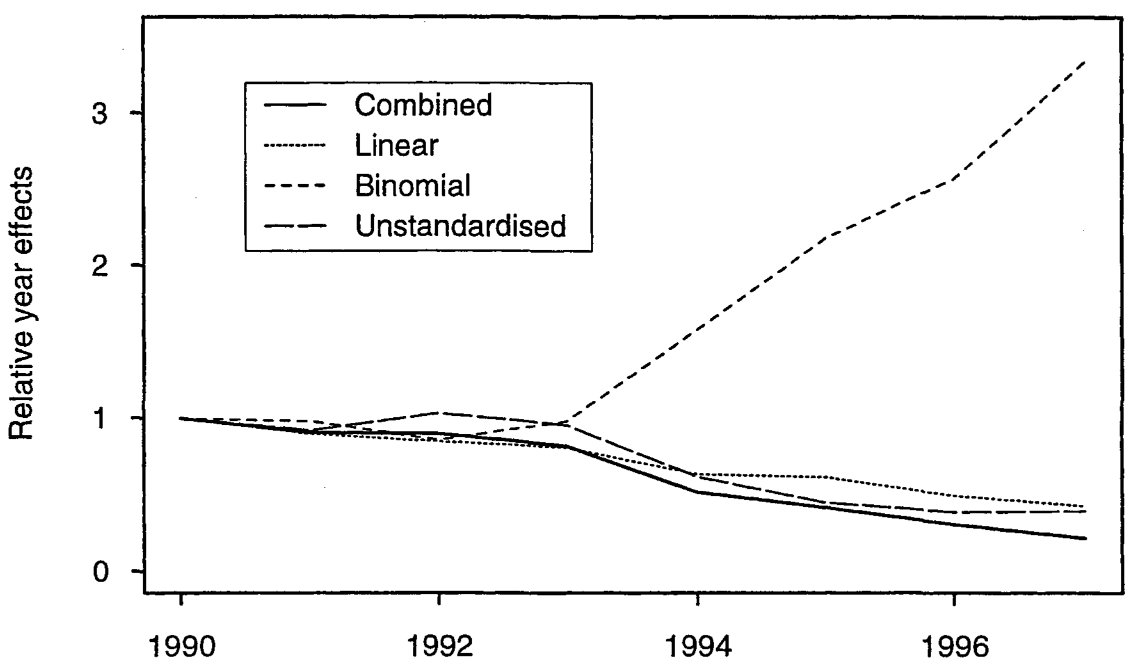

Figure 2: Comparison of relative year effects for GUR 1 East.

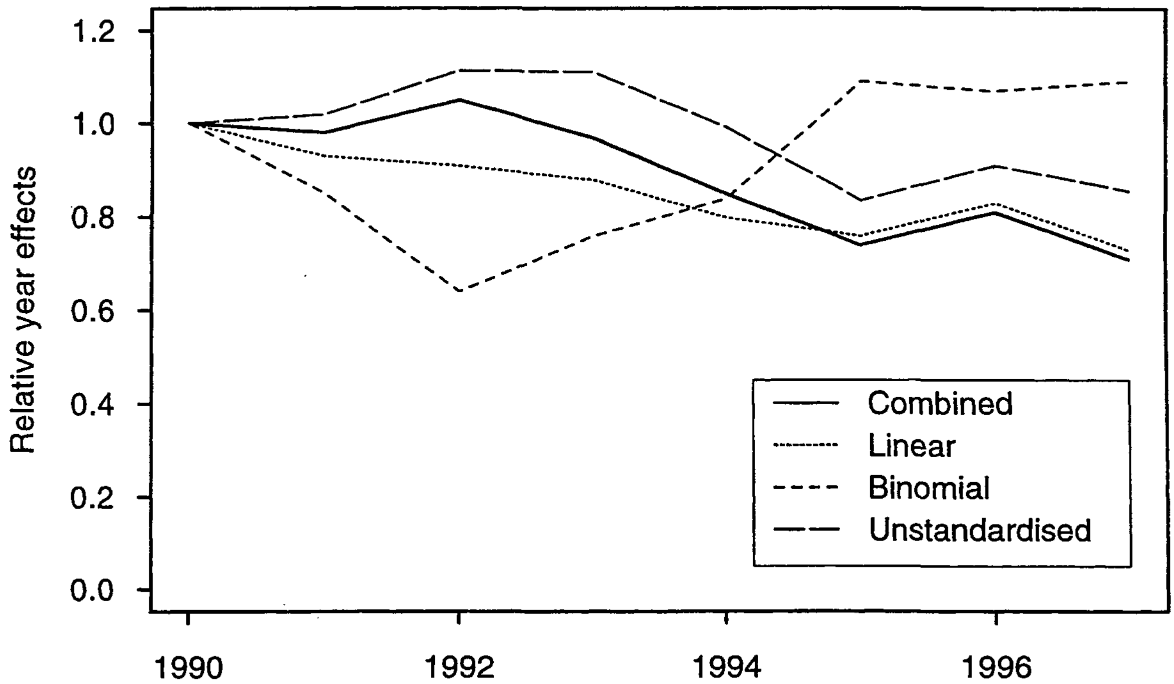

Figure 3: Comparison of relative year effects for GUR 2.

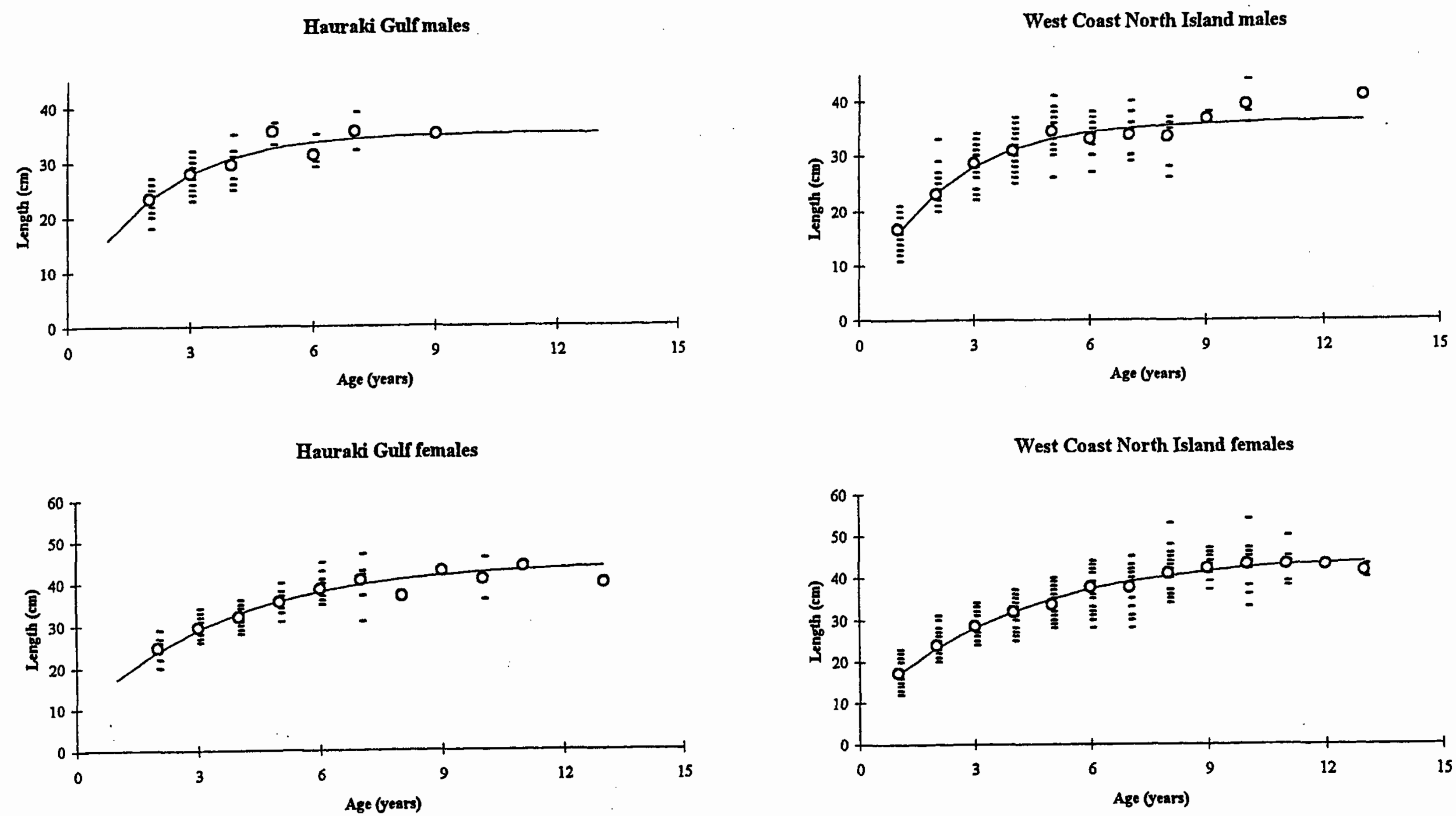

Figure 4: Age-length data, calculated mean lengths at age (o), and von Bertalanffy growth curves for male and female red gurnard from the Hauraki Gulf and west coast North Island.

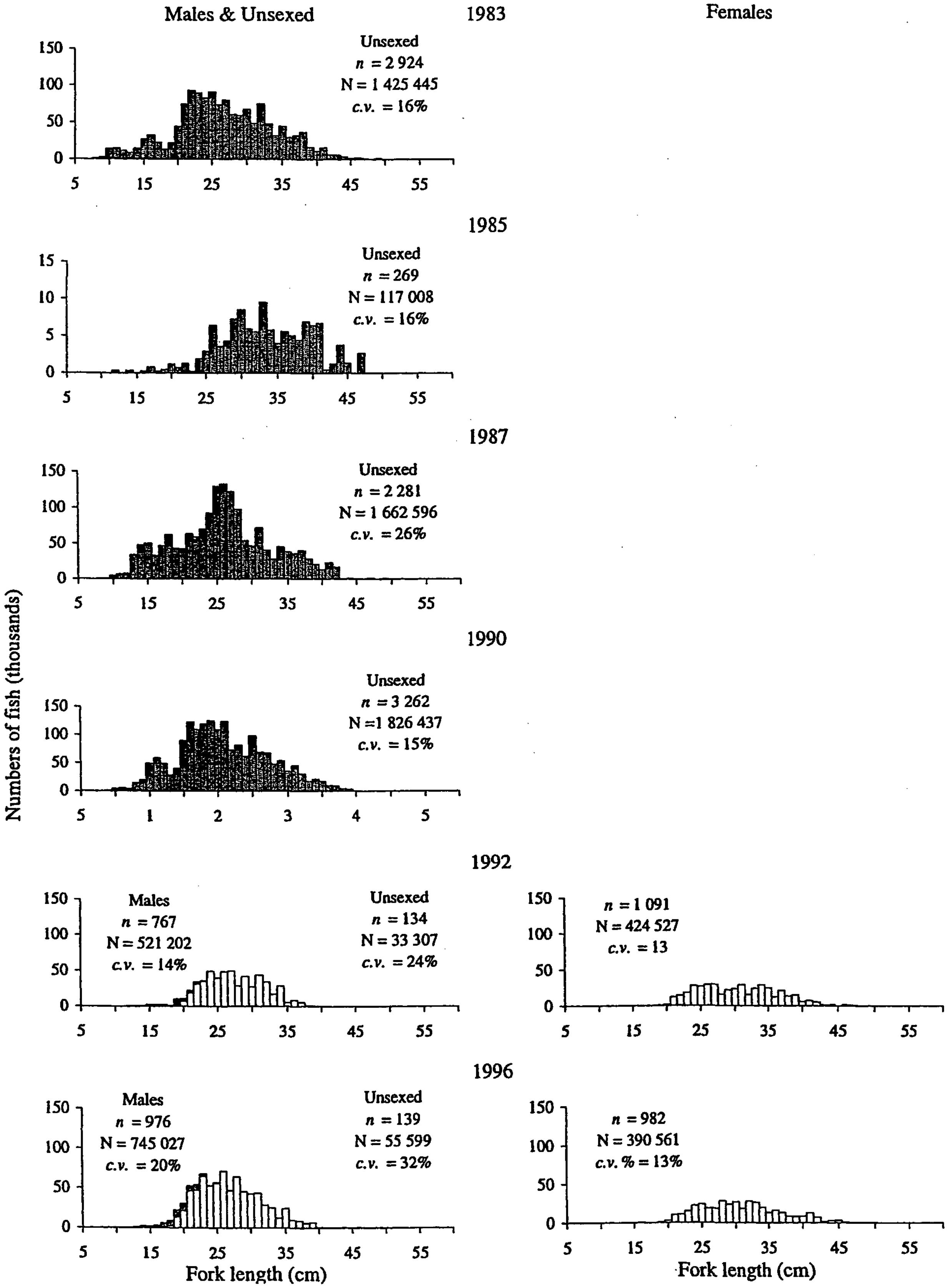

Figure 5: Scaled length frequency distributions for red gurnard from surveys in the Bay of Plenty.

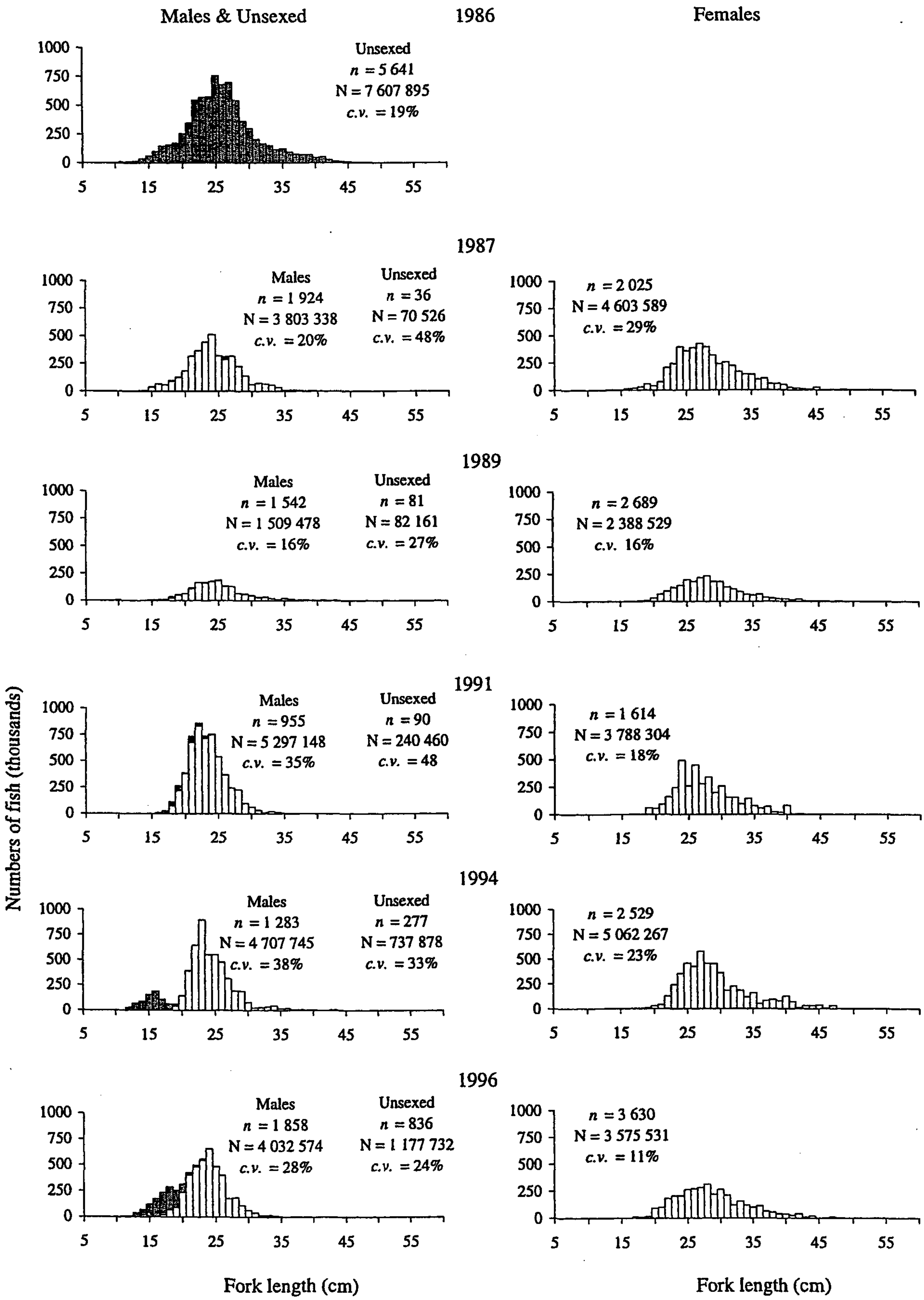

Figure 6: Scaled length frequency distributions for red gurnard (FMA 9) from surveys along the west coast of the North Island.

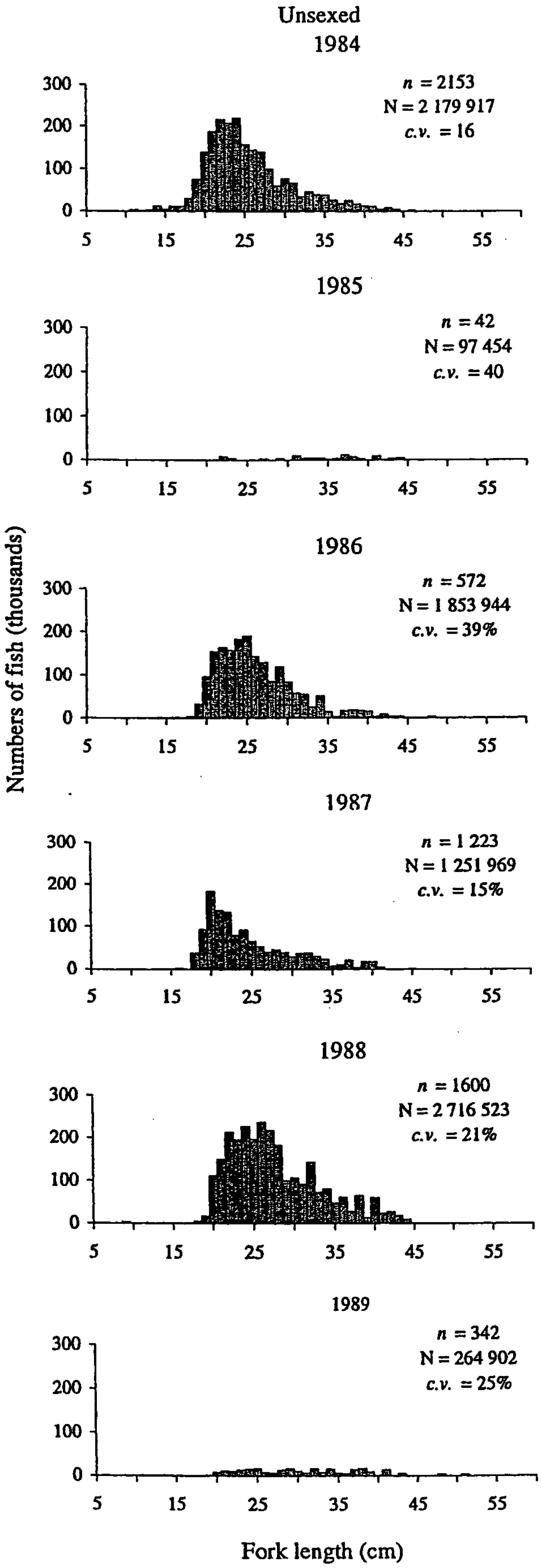

Figure 7: Scaled length frequency distributions for red gurnard from surveys in the Hauraki Gulf.

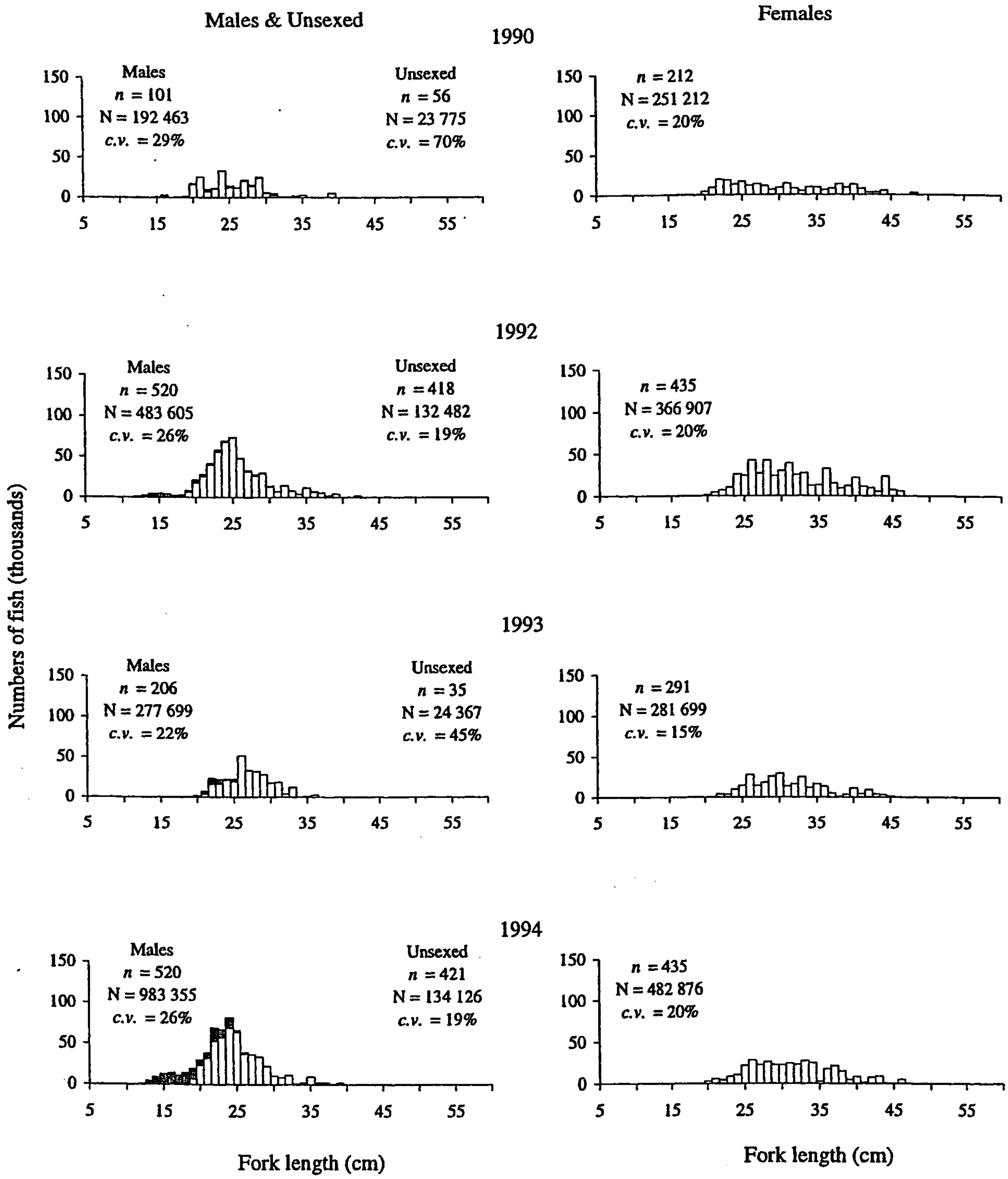

Figure 7—*continued.*

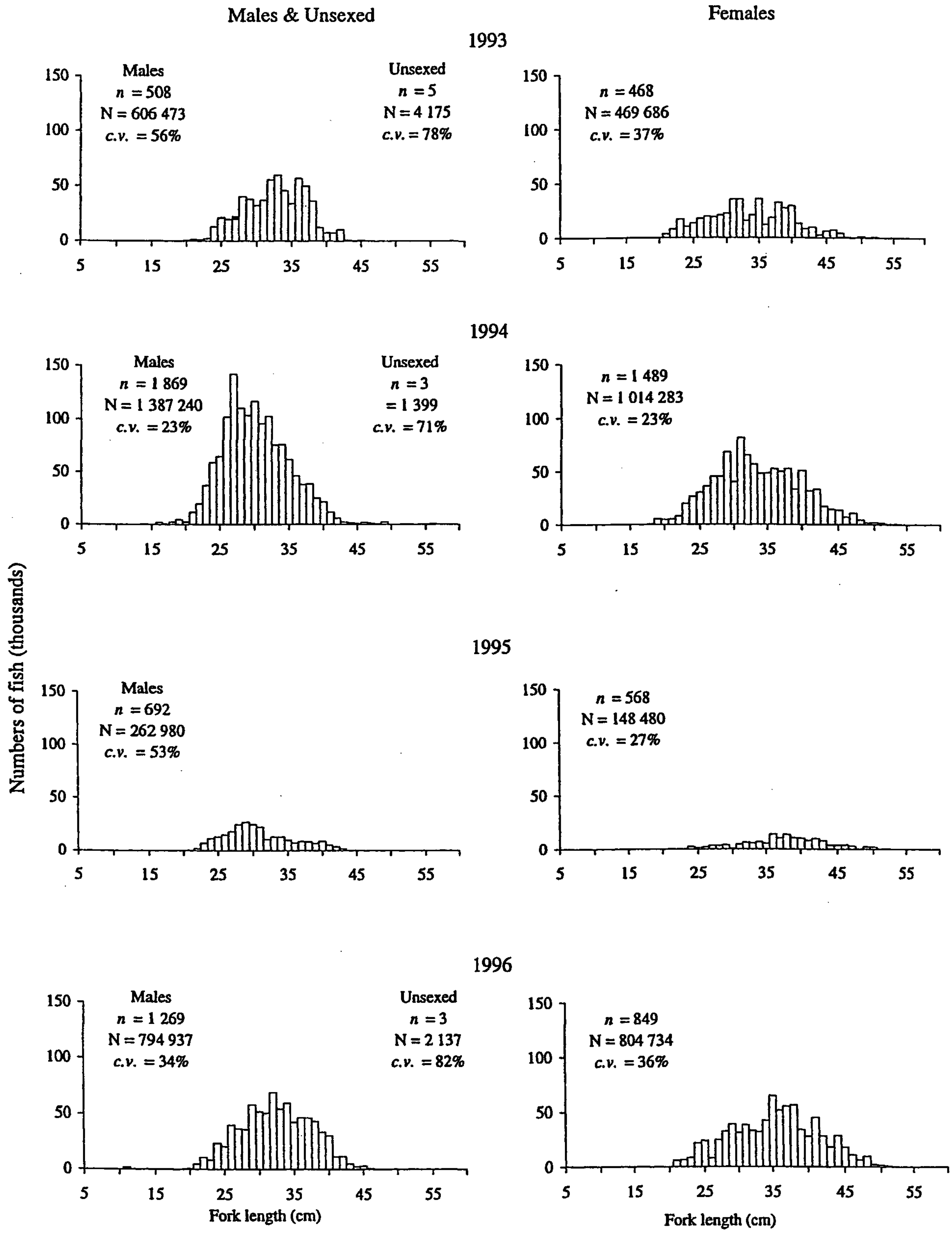

Figure 8: Scaled length frequency distributions for red gurnard from trawl surveys along the east coast of the North Island.

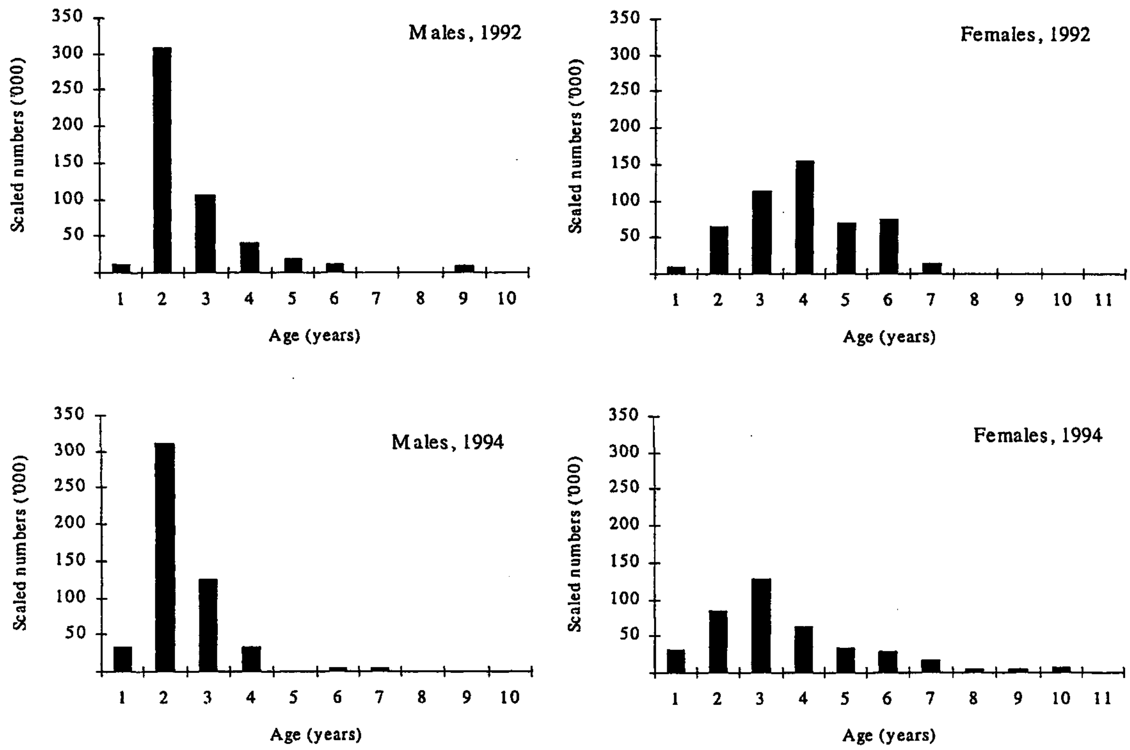

Figure 9: Scaled age frequency distribution of male and female red gurnard from trawl surveys of the Hauraki Gulf in 1992 and 1994.

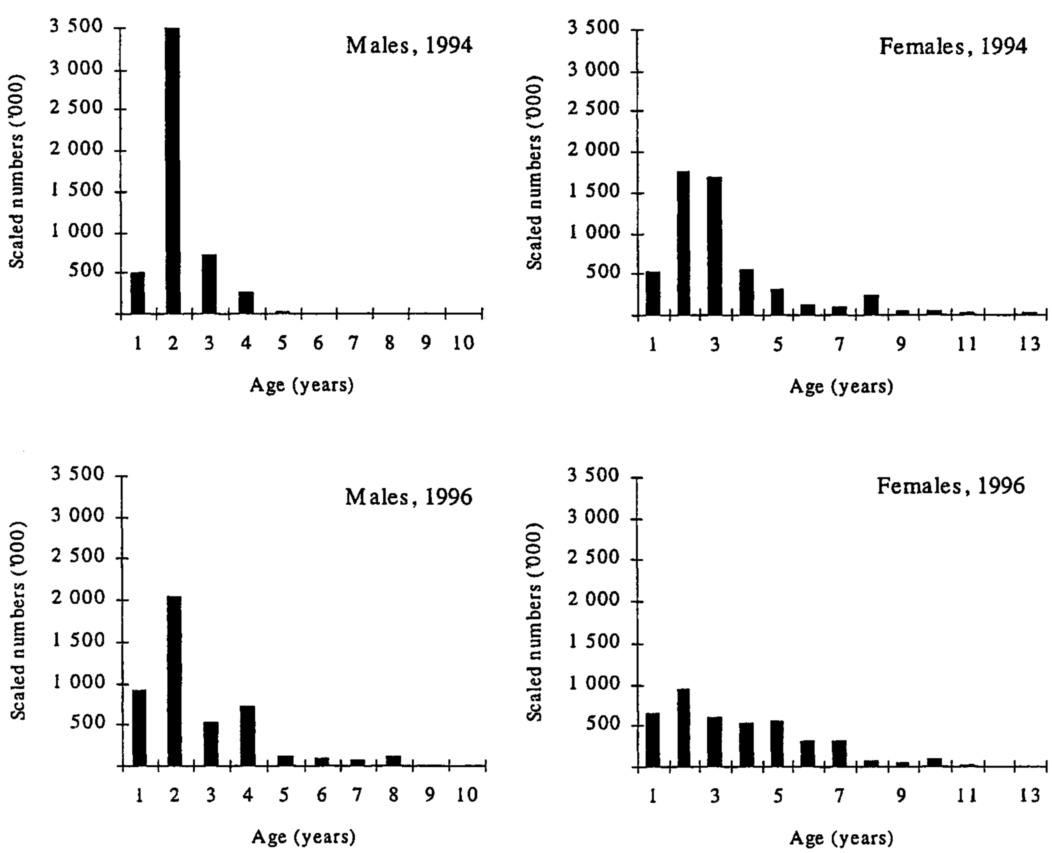

Figure 10: Scaled age frequency distribution of male and female red gurnard from trawl surveys off west coast North Island in 1994 and 1996.

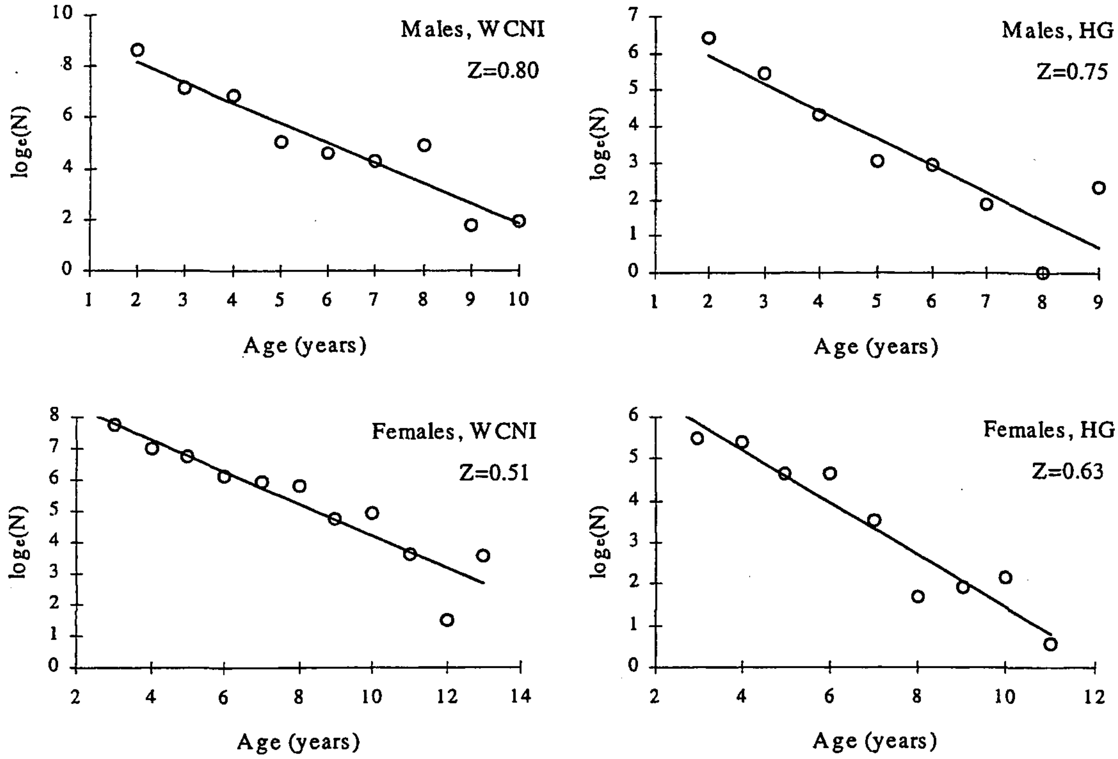

Figure 11: Estimates of total mortality (Z) for males and females from west coast North Island (WCNI) and the Hauraki Gulf (HG), from catch curve analysis.

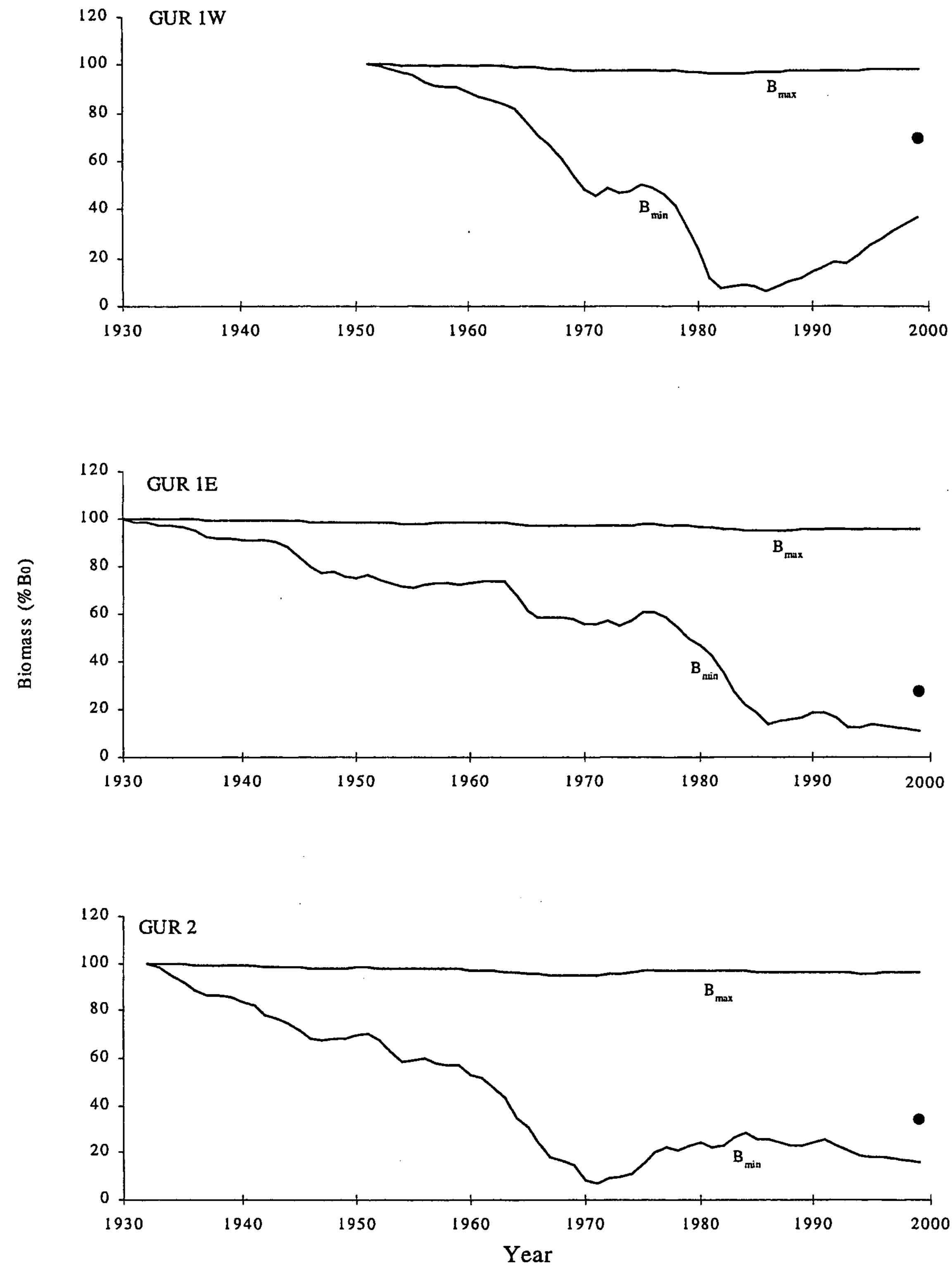

Figure 12: Trajectories for minimum (B_{min}) and maximum (B_{max}) estimates of biomass for base case red gurnard stock assessments of GUR 1W, GUR 1E, and GUR 2. The closed circles indicate the MIAEL estimates of mid spawning season biomass at the end of the 1998–99 fishing year.

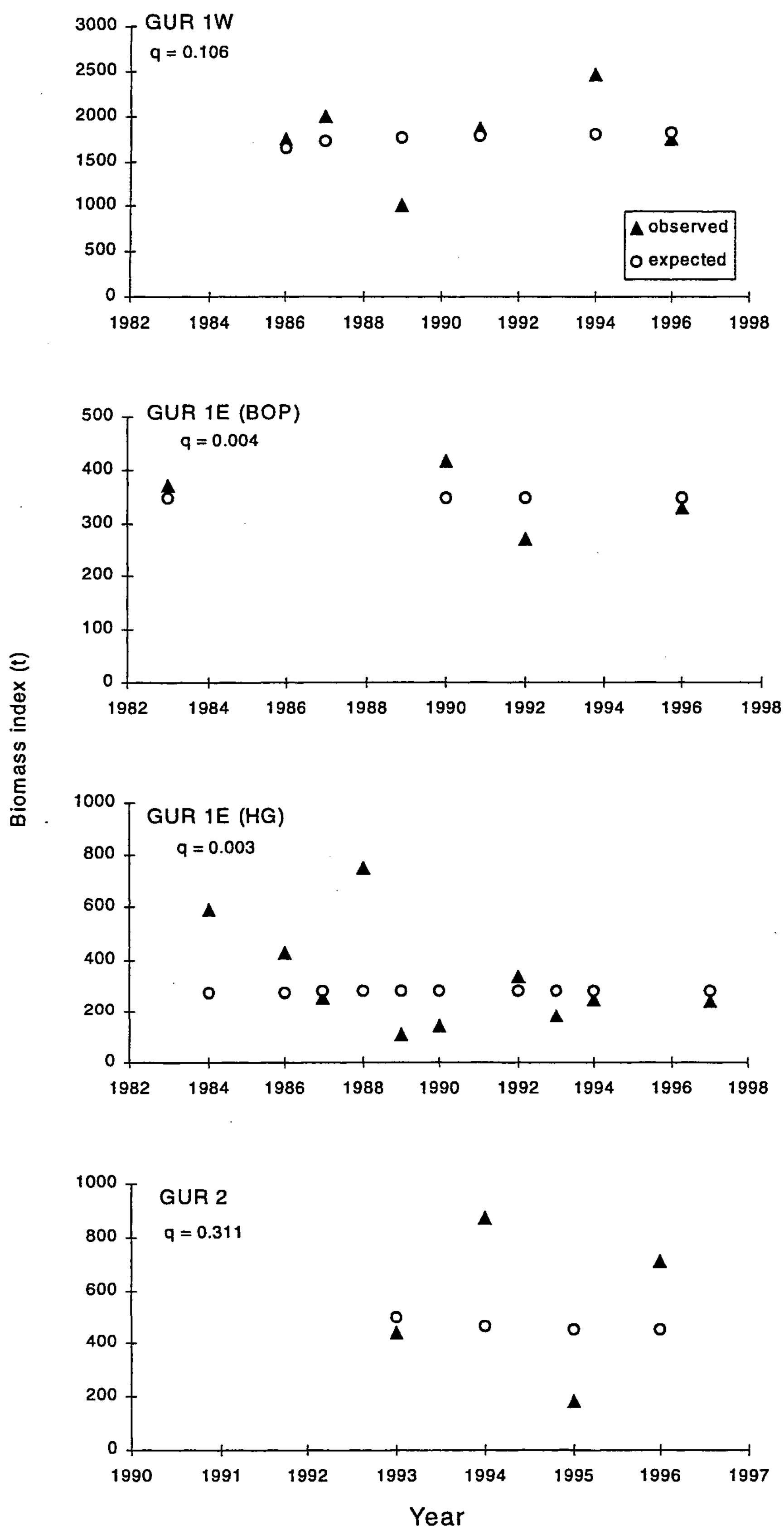

Figure 13: Fits of the trawl survey indices (observed) to the modelled biomass (expected) for the four trawl survey series, and the estimated values of *q* (catchability).

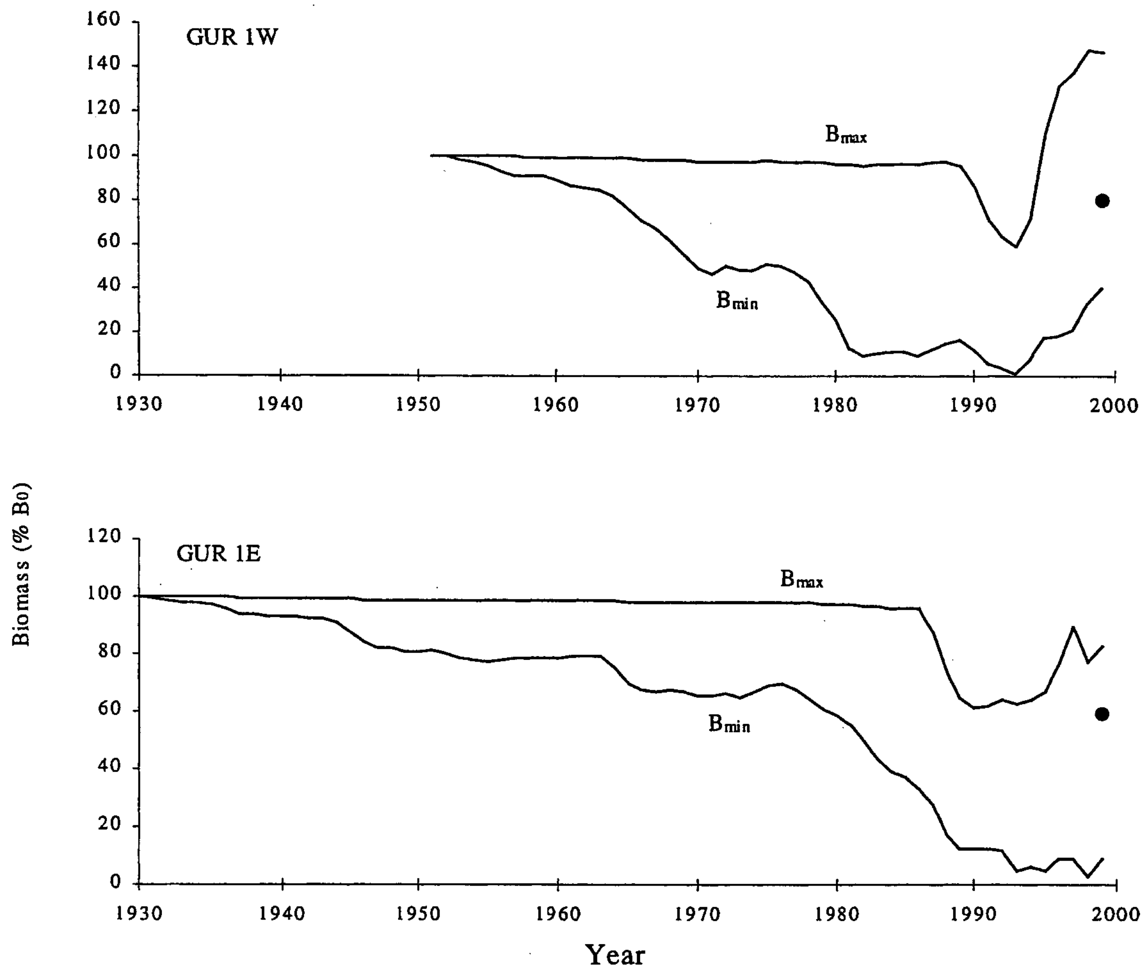

Figure 14: Trajectories for minimum (B_{min}) and maximum (B_{max}) estimates of biomass from model runs for GUR 1W and GUR 1E, when proportion-at-age data and estimates of 1+ year class strengths are incorporated. The closed circles indicate the MIAEL estimates of mid spawning season biomass at the end of the 1998–99 fishing year.

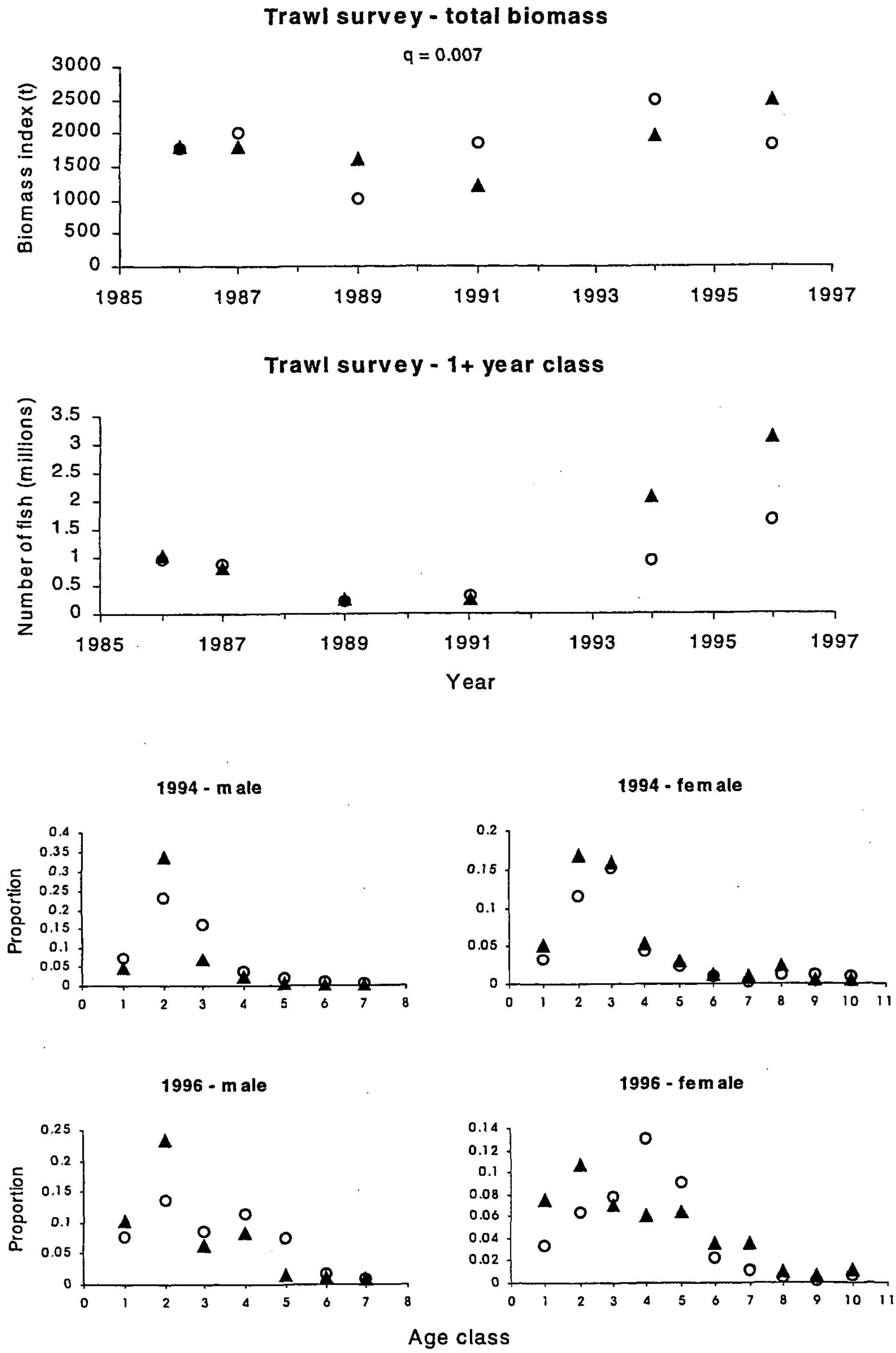

Figure 15: Fits of observed (solid triangles) and expected (open circles) data series for the GUR 1W stock, in the model run incorporating proportion-at-age data and estimates of 1+ year class strengths.

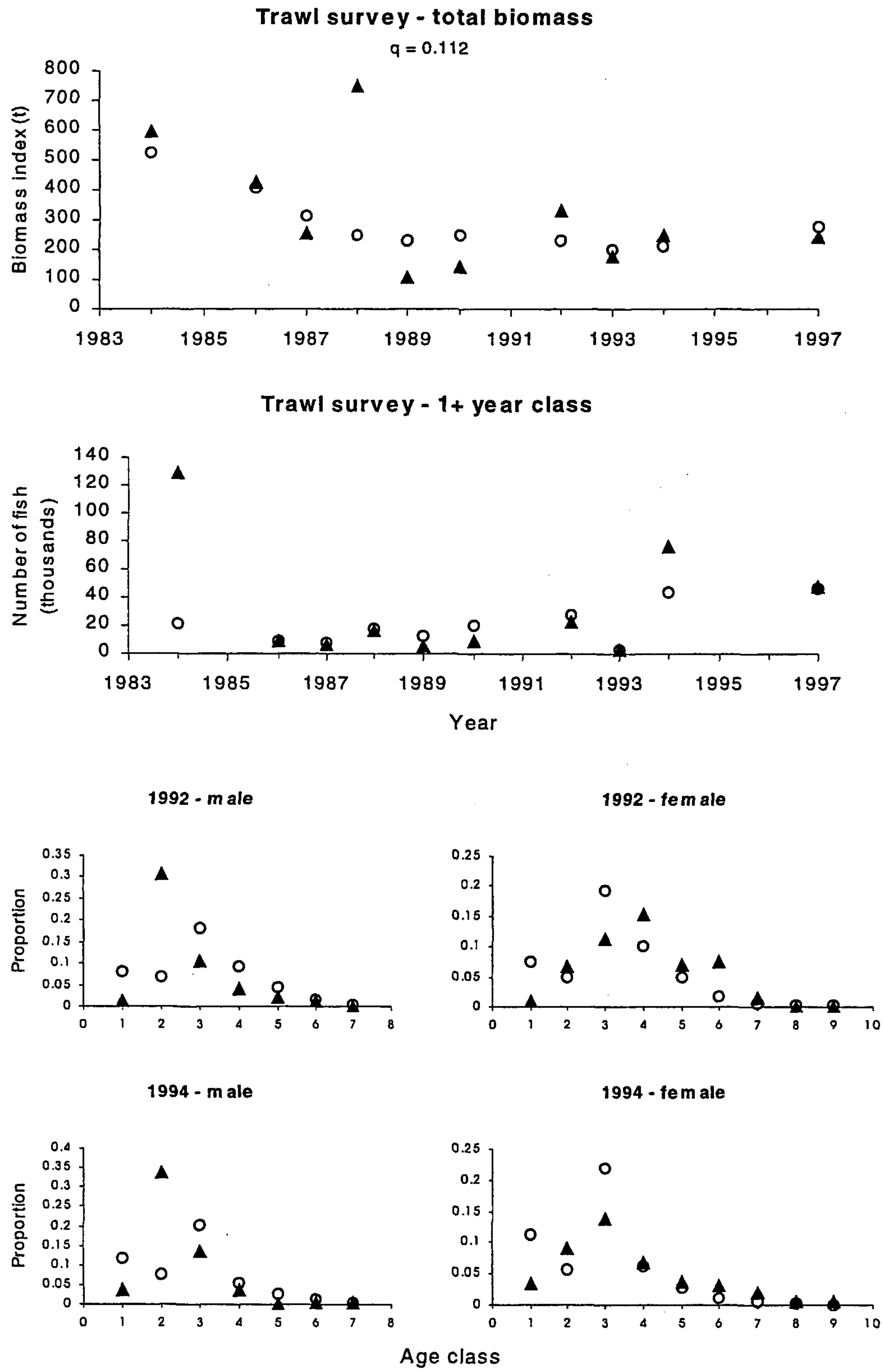

Figure 16: Fits of observed (solid triangles) and expected (open circles) data series from the Hauraki Gulf (GUR 1E), in the model run incorporating proportion-at-age data and estimates of 1+ year class strengths.

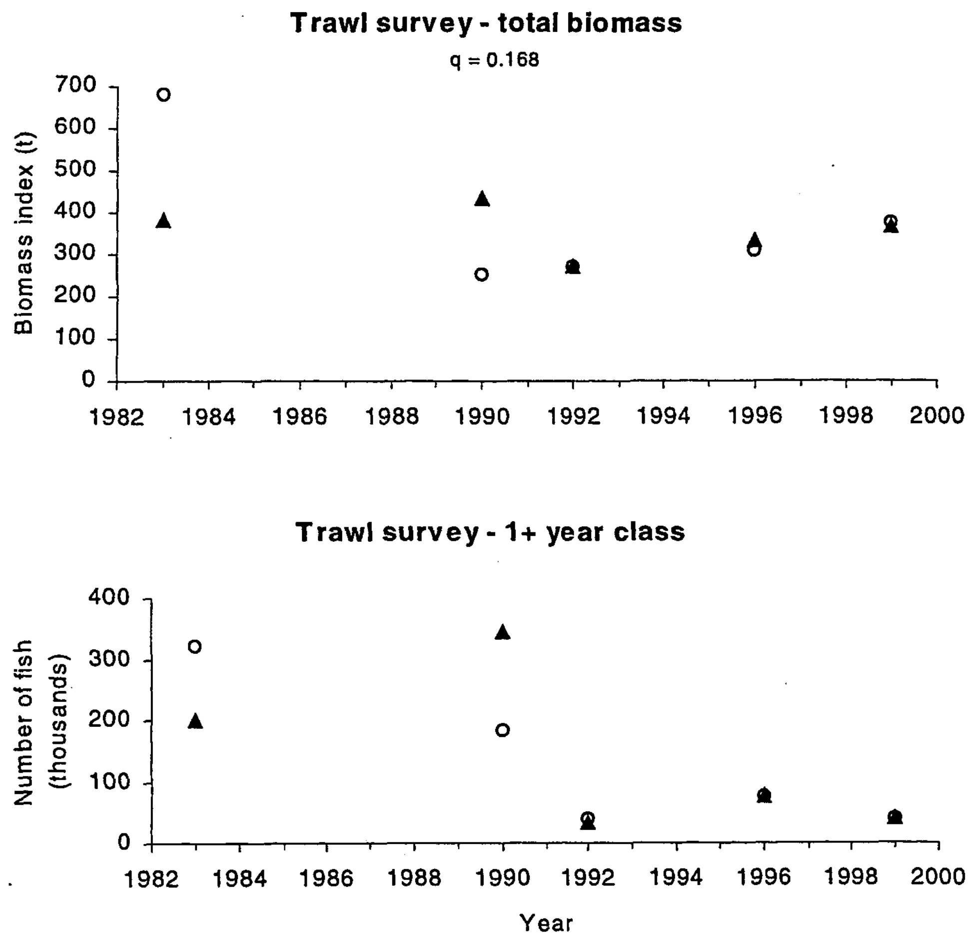

Figure 17: Fits of observed (solid triangles) and expected (open circles) data series from the Bay of Plenty (GUR 1E), in the model run incorporating proportion-at-age data and estimates of 1+ year class strengths.

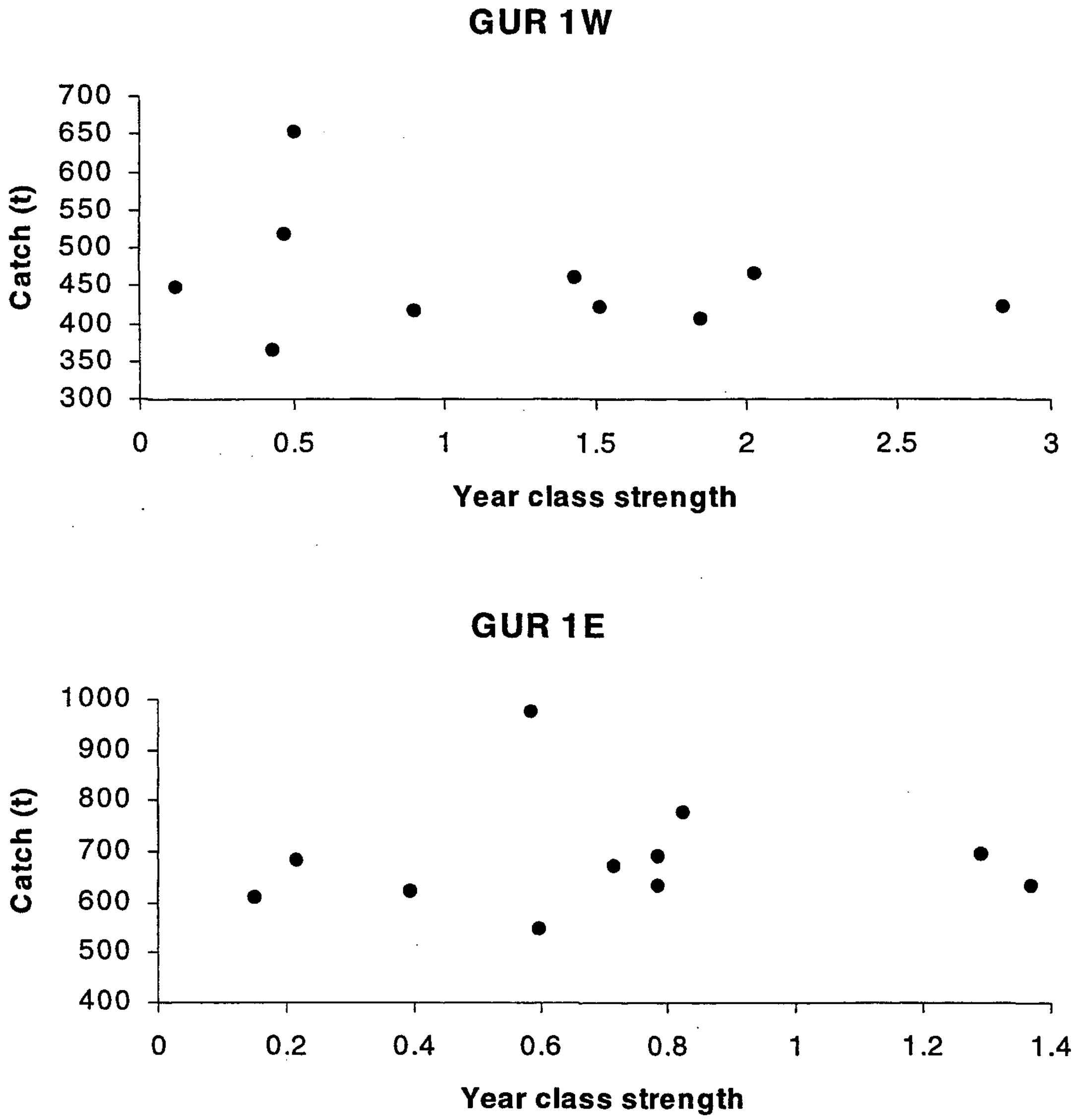

Figure 18: Relationship between the mean estimated year class strength of 3+ and 4+ fish, and commercial landings, from fishing years 1987–88 to 1997–98.

Appendix 1: Parameters used for calculation of biomass and scaled length-frequency distributions for red gurnard.

For all surveys, gear performance was set to "less than 3". For the length-weight coefficients used in the trawl survey analysis programs, *see* Table A1.1 below

Hauraki Gulf surveys (GUR 1E)

KAH8421
Areal availability changed as follows; bracketed pairs are stratum number and area (km^2):
(21, 205), (22, 464), (23, 196), (24, 168), (25, 427), (31, 115), (32, 342), (41, 2124), (50, 1129), (60, 2063)
Because: Total area survey area reduced to match 1986 and later surveys; some of the areas to be removed were at the boundaries between existing or new strata, so reductions were on a pro rata basis (Francis *et al.* 1995).
Biomass was calculated from length frequency data
Because: Catch weights were not available for 39 stations.
Stations 10, 12, 15, 22, 27, 28, 33, 34, 39, 40, 41, 43, 44, 45, 46, 47, 48, 49, 51, 52, 53, 55, 56, 58, 62, 63, 64, 65, 67, and 68 were excluded
Because: No length frequency data were available from these stations.

KAH8517
Same as KAH8421 except:
Areal availability was changed as follows; bracketed pairs are stratum number and area (km^2):
(23, 196), (27, 669), (28, 595), (31, 115), (32, 342), (41, 2124), (50, 1129), (60, 2063)
Because: Total area of survey reduced to match 1986 and later surveys, and some of the areas to be removed were at the boundaries between existing or new strata so reductions had to be on a pro rata basis (Francis *et al.* 1995).
Biomass was calculated from length frequency data
Because: First five surveys had lower mean headline height than later surveys.

KAH8613
Same as KAH8421 except that all strata were selected
Biomass estimates calculated from length frequency data
Because: First five surveys had lower mean headline height than later surveys.

KAH8716 & KAH8810
Same as KAH8613

KAH8917
Same as KAH8613 except:
Biomass estimates were calculated using catch weights

KAH9016, KAH9212, KAH9311, KAH9411 & KAH9720
Same as KAH8917

West coast North Island surveys (QMA9) (GUR 1W)

KAH8612
Strata A1, A2, A3, A4, G1, G2, G3, G4, H1, H2, H3, H4, and half of B1, B2, B3, and B4 excluded
Because: These strata are outside the area of the 1987 survey (which was used as the "base" survey).
Biomass was calculated from catch weights, with weights for stations 14 and 79 estimated from length frequency data.
Effective stratum areas were as follows; bracketed pairs are stratum number and area (km^2):
(B1, 195.17), (B2, 249.0), (B3, 121.4), (B4, 58.63)

KAH8715
All strata were used with no change to areal availability (the "base" survey)
Biomass was calculated from length frequency data using length-weight regression equation
Because: Few catch weights are available

KAH8918
Same as KAH8715 except:
All of strata GEB1, GEB2, WCN2, WCN3, WCS4, WCS5, and 50% of WCN1 and WCS1, and 70% of WCS2 excluded
Because: These strata are outside area of 1987 survey.
Effective areas (km^2): WCN1 = 1177.0; WCS1= 1319.5; WCS2 = 649.5
Biomass estimates were calculated from catch weights

KAH9111
Same as KAH8715 except:
All of strata A25, A50, A100, A200, B25, B200, C200, E200, F50, F100, F200, G25, G50, G100, H25, H50, I25, I50, J25, and 50% of strata B100 excluded
Because: These strata are outside area of 1987 survey.
Effective area: B100 = 665.5 km^2
Biomass estimates were calculated from catch weights

KAH9410
Same as KAH8715 except:
All of strata A25, AA50, A100, A200, B25, B200, C200, E200, F50, F100, F200, G25, and 50% of strata B100 excluded
Because: These strata are outside area of 1987 survey.
Effective area: B100 = 665.5 km^2
Area of stratum BB50 set at 323 km^2
Biomass estimates were calculated from catch weights

KAH9615
Same as KAH9410 except
The effective area of stratum B100 is 666 km^2

Bay of Plenty surveys (GUR 1E)

KAH8303
Doorspreads were calculated from warp length using the equation from Langley (1994)
dist_doors = 88.8214 × (1–e(–0.00970 × (warp_lgth + 7.330)))
Because: Actual doorspreads were not available, and the constant doorspread used in previous analyses (79 m) inaccurately estimates area swept.
Stratum 9 excluded
Because: Area of 1987 survey was used for all analyses and stratum 9 is outside that area.
Biomass calculated from length frequencies and percent sampled
Because: Few catch weights were available.

KAH8506
Same as KAH8303 except:
Stratum 0090 excluded
Because: Area of 1987 survey was used for all analyses and stratum 0090 is outside that area.

KAH8711
Same as KAH8303 except:
Only strata 11, 12, 21, 22, 23, 30, 40, 51, 52, 360 were included
Because: Other strata were in the Hauraki Gulf (as part of a combined survey).

KAH9004
Same as KAH8303 except:
Catch weights were available, but biomass was calculated from length frequencies and percent sampled for consistency.
No strata were excluded

KAH9202
Same as KAH9004 except:
Stratum MNGM excluded
Because: Area of 1987 survey was used for all analyses and stratum MNGM is outside that area.

KAH9601
Same as KAH9004 except:
Doorspreads used were recorded doorspreads
Because: Actual doorspreads were recorded using Scanmar gear.
Catch weights were available, but biomass was calculated from length frequencies and percent sampled for consistency with other surveys.
There are no length frequencies taken for station 56. This resulted in no biomass for stratum 909N. However, the biomass estimate for stratum 909N using recorded catch weights is 0.14 t.

West coast North Island surveys (QMA8) (GUR 8)

KAH8918
Includes strata WCS4, WSC5, 50% of WCS1 and 70% of WCS2
Because: These strata cover the area of GUR 8.
Effective areas (km^2): WCS1= 1319.5; WCS2 = 1515.5
Biomass estimates were calculated from catch weights

KAH9111
Same as KAH8918 except:
Includes strata F50, F100, and G25 only
Because: These strata cover the area of GUR 8.
Biomass estimates were calculated from catch weights

KAH9410 & KAH9615
Same as KAH9111

East coast North Island surveys (GUR 2)

KAH9304
Biomass calculated from catch weights
Strata 1, 2, 3, 4, 5, and 6 excluded
Because: Strata were outside the area of later surveys.
Areal availability for strata 14 and 18 reduced to match areas of later surveys
Effective areas (km^2): 14 = 655.2, 18 = 762.9

KAH9402
Same as KAH9304 except
All strata included and no change to areal availability

KAH9502 & KAH9602
Same as KAH9402

Table A1.1: Length-weight coefficients used in the trawl survey analysis programs. The equations are $W = aL^b$ or $W = aL^bL^{c(\ln L)}$ where W = weight (g) and L = length (cm). –, not calculated

Survey	Area	*a*	*b*	*c*	*n*	Range (cm)
KAH9205	ECSI	0.00166	3.4784	–	227	19.4–54.6
KAH9502	WCSI	0.00576	3.1713	–	765	20–56
KAH8303[1]	BOP	0.63803	0.5923	0.3596	162	8–45
KAH9701[2]	WCSI	0.00528	3.1935	–	780	19–51

[1] Used for red gurnard in all west coast North Island, Hauraki Gulf, and Bay of Plenty surveys
[2] Used for red gurnard in all east coast North Island surveys