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EXECUTIVE SUMMARY

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This report documents research completed under Objectives 2 and 4 of MFish Research Project SNA9805. Its objective was to obtain predictors of relative year class strength from temperature data for the snapper (*Pagrus auratus*) Fishstock SNA 2 and Tasman-Golden Bay (Fishstock SNA 7).

Because the only reliable sea surface temperature (SST) data (i.e., satellite remote sensing data) were unavailable over the full time frame required, air temperature data from a number of weather stations were examined for their ability to provide proxy SST data. Correlation analysis, comparisons of absolute values, and cumulative sum analysis were used to test for stationarity and consistency between series. Air temperature data recorded at Napier-Nelson Park and Waipukurau weather stations satisfied the stationarity and consistency tests for SNA 2; those recorded at Appleby and Nelson Aero stations satisfied the tests for SNA 7.

A total of 34 sets of age data were used (3 for SNA 2 and 31 for SNA 7). Most were from research voyages and commercial landings; one was from a tag-recapture experiment. Some were simple random samples from a single trip, others were weighted estimates from stratified samples. Most datasets were the same as used in previous studies. Some otoliths were re-read for SNA 2 and SNA 7 estimates in 1997–98 and 1998–99. All age samples were expressed as proportions at age. Estimated coefficients of variation (c.v.s) were used to derive equivalent simple random sample sizes for the stratified samples to enable the same treatment of all samples.

A maximum likelihood estimator that assumed multinomial variability was developed to determine relative year class strength. Choice of the best SST proxies from those that satisfied the stationarity and consistency tests, and the choice of which months to use as predictors, were based on the maximum likelihood value. Scaled residuals were plotted against age to determine whether there were any patterns that might indicate process error. Quantile plots were used to examine whether the data were consistent with the assumption of multinomial variability.

For both SNA 2 and SNA 7 we obtained the best model fit (base case) with minimum age = 7 and for the 6-month mean air temperature (Napier-Nelson Park and Appleby for SNA 2 and SNA 7 respectively) from September to February. Only 3-month and 6-month means were tried. Negative log-likelihoods for the fits without the temperature terms were significantly higher for both Fishstocks; they also increased as the minimum age was changed from 7 and as the start of the 6-month period was changed from September. Base case residuals showed satisfactory patterns when plotted against age, and base case quantile plots were also satisfactory, although there was a large proportion of zero observations for both the SNA 2 and SNA 7 datasets.

The estimated slopes of the logarithm of recruitment with respect to temperature, β = 0.508 for SNA 2 and β = 0.651 for SNA 7, were similar to those estimated previously within the Hauraki Gulf/Bay of Plenty stock assessment model (β = 0.534, February–June), but higher than that estimated for SNA 8 (β = 0.296, December–January).

1. INTRODUCTION

1.1 Overview

This work was aimed at obtaining predictors for relative year class strength from temperature data for snapper (*Pagrus auratus*) in Fishstock SNA 2 and in Tasman-Golden Bay, which is part of Fishstock SNA 7 (Figure 1) (no data used in the SNA 7 analysis are from outside Tasman-Golden Bay, so the terms Tasman-Golden Bay and SNA 7 are used synonymously in this document). This work was carried out under Objectives 2 and 4 of MFish Research Project SNA9805,

- To determine the relationships between snapper year class strength and water temperature in SNA 2 and Tasman-Golden Bay.

For SNA 7, it would be helpful in establishing the extent to which the stock has rebuilt since the mid 1980s to have estimates of the relative strengths of the recently recruited year classes. Two sets of estimates for each stock were available from the 1997–98 and 1998–99 sampling programmes (SNA9703 and SNA9805).

For both SNA 2 and SNA 7, the ability to predict relative year class strength from water temperature would improve short-term predictions of change in stock biomass. It would also allow the prediction of changes in the size of fish in the fisheries and improve the quality of the estimate of the past biomass trajectory. The greatest potential is perhaps the ability to predict substantial changes in average yield, which might correspond to any systematic changes in water temperature over a decadal time scale, if such were to occur.

A good predictive relationship between water temperature and year class strength has been established for Hauraki Gulf snapper based on work by Francis et al. (1997). The mechanism driving this relationship is not known. There is evidence that similar relationships exist for other snapper stocks. Because the causal mechanism is unknown, it is not known whether Hauraki Gulf water temperature is a fortuitous proxy for a complex hydrological process which favours snapper recruitment or whether the causality is more direct.

Water temperature varies spatially and seasonally throughout Tasman and Golden Bays. The use of air temperature as a proxy for water temperature gave a significant but imprecise predictor of year class strength for Tasman-Golden Bay snapper (Annala & Sullivan 1996, Harley & Gilbert 2000). The fact that these fits were much poorer than the comparable recruitment air temperature relationship for the Hauraki Gulf suggests that either the water temperature relationship is not as strong or that the air temperature data gave a poorer proxy for water temperature.

1.2 Previous research

There have been a number of studies investigating the relationship between year class strength in fish species and environmental factors in recent years. They include investigations of both marine species (e.g., Watanabe et al. 1999, Begg & Marteinsdottir 2000, Oeberst & Bleil 2000) and freshwater species (e.g., Jackson 1999, Jackson & Noble 2000, Grenouillet et al. 2001), based on a range of factors shown to influence recruitment, including water temperature, oxygen concentration, circulation patterns, and the severity of spring flooding. In New Zealand, three studies on marine species have provided information on snapper (Francis et al. 1997), southern gemfish (*Rexea solandri*) (Renwick et al. 1998), and hoki (*Macruronus novazelandiae*) (Livingston 2000).

Maceina (1997) used residuals from log-linear regression of catch-curves to assess year-class strength in fish. The approach developed here was similar, but we used maximum likelihood for estimation. Log-linear regression does not deal properly with zero values and is statistically less satisfactory.

2. DATA

2.1 Background

Two sources of sea surface temperature (SST) were available: time series of direct measurements (ships' measurements) on a broad areal scale from the NIWA climate database (CLIDB), and satellite remotely sensed data from the United States National Weather Service's Climate Analysis Center (CAC). It was known that the direct measurement data are somewhat less reliable due to missing values and possible calibration problems, but cover a long time period (1920s to the present) — their lower quality was confirmed by Taylor (1997) and they were not included in the analyses. The satellite data are more consistent, but began only in 1982. They were available as monthly means averaged over 2° latitude by 2° longitude squares (2° squares).

Air temperature has been recorded more reliably at New Zealand climatological stations. It is likely to be a good proxy for water temperature. Air temperature time series were investigated as potential predictors of year class strength. Their suitability as a proxy for SST was investigated by examining the relationship between the two for the years that CAC SST data were available.

As described by Basher & Thompson (1996), the remote sensing data were obtained from a bulletin board of meteorological analyses operated by the CAC. Information presented at the bulletin board describes the following process in detail, which is completed before the data are posted. In brief, data are derived by linear interpolation of weekly optimum interpolation (OI) fields to daily fields, with the daily values then averaged over a month. The OI SST uses in situ (ship and buoy data) and satellite SSTs. The satellite data are adjusted for biases using the method of Reynolds (1988) and Reynolds & Marsico (1993). The OI analysis was described by Reynolds & Smith (1994).

From 1981 to 1989 the satellite data were obtained from analysis of operational data from the National Environmental Satellite, Data and Information Service (NESDIS) produced by the University of Miami's Rosentiel School of Marine and Atmospheric Sciences; the in situ data consist of radio and logbook reports and were obtained from the Comprehensive Ocean Atmosphere Data Set. From 1990 to the present, the satellite observations were obtained from NESDIS and the in situ data from radio messages carried on the Global Telecommunications System.

Age data were available from a variety of sources and include those used previously by Harley & Gilbert (2000), Blackwell et al. (2000), and Gilbert (1999). The term age class refers to all fish of a particular age in a particular year. The method described below requires a set of samples, taken at various times, of proportion at age in a population, i.e., a measure of the relative size of each age class. The process of taking fish from the population for a particular estimate may entail selectivity dependent on age. The method can use such estimates, provided the selectivity broadly follows a systematic pattern (described below).

A catch at age sample is a vector containing estimated proportions of fish in an annual catch, by age. Catch at age samples obtained annually from landed catch for SNA 2 for the calendar years 1992, 1998, 1999, and Tasman-Golden Bay for 1969, 1970, 1971, 1972, 1974, 1978, 1979, 1980, 1984, 1987, 1993, 1998, and 1999 were used here. In what follows the term *catch at age sample* will be used to refer to the estimated vector of catch at age for a fishing year, even if it was obtained from samples from several landings. For single landings and research voyages simple random samples were usually taken. Where the catch had been divided, stratified sampling was sometimes used. For multiple landings, vessel and season strata were defined and simple random samples from vessels were weighted by landing and then stratum estimates were further weighted by total stratum landings. The 1993 SNA 7 estimates were calculated from an age length key (Davies & Walsh 1995, Walsh et al. 1995). Stratified random samples were taken from the landed catch to obtain estimated proportions at length. Random subsamples were taken to obtain an age length key, i.e., estimated proportions at age for each length. This was applied to the proportion at length estimates to give estimates of proportions at age. The coefficient of variation (c.v.) of each proportion at age estimate (due to sampling variability) was also calculated.

Plots of cumulative sums of monthly temperature deviations from the mean are used in this work as heuristic tests for nonstationarity in a series and consistency between series. The plots are characterised by two patterns of variability (e.g., see Figure 5): a regular, high frequency, annual periodicity caused by seasonal variation, which provides little diagnostic information in this context; and sometimes an irregular, low frequency fluctuation, which is the feature of interest.

2.2 Sea surface temperature

Summaries were extracted from the CAC database for the period 1982–99. Summaries were obtained for eight 2° squares: seven between East Cape and the Wairarapa coast, and one in Tasman-Golden Bay, centred on the following points:

- Area 1, 178° 30' E, 37° 30' S.
- Area 2, 178° 30' E, 38° 30' S.
- Area 3, 179° 30' E, 38° 30' S.
- Area 4, 177° 30' E, 39° 30' S.
- Area 5, 178° 30' E, 39° 30' S.
- Area 6, 176° 30' E, 40° 30' S.
- Area 7, 177° 30' E, 40° 30' S.
- Area 8, 173° 30' E, 40° 30' S.

Datasets were compared two at a time using correlation analysis (correlation coefficients were calculated using deviations from the long-term monthly means for each time series), plots of their absolute values, and plots of the cumulative sums (function "cumsum" in the S programming environment) of the variation in the air temperature series from their long-term means. The cumulative sum comparative plot is expressed in S notation as

$$plot(cumsum(temp_1), cumsum(temp_2) - cumsum(temp_1) * mean_2 / mean_1)$$

where $temp_1$ and $temp_2$ are the data series and $mean_1$ and $mean_2$ are their respective long-term means. If the series are linearly related, the line will deviate randomly around a horizontal straight line. If there is a change in the relationship, such as might be caused by a change in the mean of one series, the line will kink at the change.

The geographical relationship between Areas 7 and 8, and the weather stations whose air temperature data were considered for their use as proxies of SST in Area 7 and 8, are shown in Figure 2.

2.3 Air temperature

Climatological stations with the potential to provide appropriate data for SNA 2 and 7 were identified in CLIDB by listing those closest to Napier and Gisborne (representing SNA 2), and Motueka and Picton (representing SNA 7). Sometimes, data collection had been continued at a site, or close to the original site, by stations with names that differed from the original. For example, data were collected at the *Blenheim* station from April 1932 to August 1985, at the *Blenheim Research* station from August 1985 to May 1996, and at the *Blenheim Research automatic weather station (AWS)* from June 1996 to April 2000. In these cases, datasets were concatenated to give a single time series; concatenated stations are referred to below as single stations.

There was overlap in the time series from some stations whose data were to be concatenated. For completeness, time series containing the different combinations of overlap were included in the exploratory data analyses (EDA), although there was little difference between them. In all cases, missing values were interpolated as the mean of the two values immediately preceding and following the missing value.

The EDA was aimed at identifying any systematic bias in the data caused by shifts between or changes at sites or replacement of recording equipment in the climatological stations. This was of particular concern in stations from which the aggregated datasets were derived, where changes in site location were known to have occurred. The EDA was performed by examining time series plots of the cumulative sum of the difference between recorded value (air temperature) and the long-term mean of air temperature, expressed in S notation as:

$$plot(t_1 : t_2, cumsum(temp_1 - mean_1))$$

where t_1 and t_2 are the beginning and end years of the time series $temp_1$. If the series deviates randomly around its mean, the line will deviate randomly around a horizontal straight line. If there is a change in mean, the line will kink at the change.

Choice of the most appropriate air temperature time series for each Fishstock was based on its similarity to the nearest SST dataset (using time series plots of absolute values, correlations and cumulative sum comparative plots), the requirement that it covered the period of the ageing data, and the proximity of the weather station (see Figure 2). Because it was difficult to separate some stations based on these criteria alone, two stations were chosen for each Fishstock (Waipukurau Aero and Napier-Nelson Park for SNA 2; Appleby and Nelson Aero for SNA 7), with the final choice based on comparative plots of the two and consideration of their goodness of fit in the model runs. Data from Kelburn weather station were also included because of their long time series with no missing data within the periods of interest, their similarity to the other four datasets, and the "average" proximity of Kelburn to both Fishstocks.

Air temperature time series in each Fishstock were compared using time series plots of absolute values and cumulative sum comparative plots. The four time series were also compared with the Kelburn dataset.

2.4 Use of air temperature as a proxy for SST

We examined the correlation coefficients between the selected air temperature series in each area (Napier-Nelson Park for SNA 2, Appleby for SNA 7) and the respective SST time series (from Area 7 for SNA 2, Area 8 for SNA 7). Correlation coefficients were calculated from deviations from the long-term monthly means for each time series. Plots of absolute values for these air temperature/SST combinations, and cumulative sum comparative plots, were used to determine whether their relationships remained constant over time.

2.5 Age data

A total of 34 sets of age data were used — 3 for SNA 2 and 31 for SNA 7 (Table 1). Most were from research voyages or commercial landings; one was from a tag-recapture experiment. Some were simple random samples from a single trip, others were weighted estimates from stratified samples. Most datasets were the same as used in previous studies. Some, otoliths were re-read for SNA 2 and SNA 7 estimates in 1997–98 and 1998–99.

3. MODEL

3.1 Multinomial maximum likelihood method

The statistical distribution of an age sample depends on how fish were distributed in the population (commercial and research catch), how they were sampled, and how the estimates were calculated. Here our estimates were obtained by simple random sampling or by stratified random sampling of the landed catch. We expressed all estimates as proportions at age. To enable us to treat all the samples equivalently we used the estimated c.v.s to derive an equivalent simple random sample size for the stratified samples. This was done by equating the estimated variance of the mean age with the simple random sample variance.

Let i denote the proportion at age sample,
let a denote the age in years of fully recruited fish (knife edge recruitment is assumed),
let p_{ia} denote the estimate of proportion at age a from sample i,
let c_{ia} denote the estimate of the c.v. of p_{ia}, and
let M_i denote the equivalent sample size,

Then

$$\text{Estimated variance} = \text{Simple random sample variance}$$

$$\therefore \sum_a a^2 p_{ia}^2 c_{ia}^2 = \sum_a \frac{a^2 p_{ia}(1-p_{ia})}{M_i}$$

$$\therefore M_i = \frac{\sum_a a^2 p_{ia}(1-p_{ia})}{\sum_a a^2 p_{ia}^2 c_{ia}^2}$$

The simple random samples were each taken from single landings. To allow for heterogeneity between landings, i.e., similarity between fish within a landing, we arbitrarily reduced the actual sample size by a factor of 5 to give the effective sample size.

For each spawning year, the number of fish that subsequently recruit is proportional to a relative year class strength index, ρ_y, that we assume to be a function of SST,

$$\rho_y = \alpha e^{\beta T_y}$$

where T_y is SST for year y, β is an estimated parameter and α is unknown and not estimated.

The proportions of fish at age in each sample are determined by these indices and by a recession coefficient that gives the proportionate annual reduction in numbers in each successive age class. This coefficient is the mean total mortality that the stock has suffered, but may be confounded with a selectivity relationship specific to the sample. If the logarithm of the selectivity was linearly related to age, the "total mortality" would be the sum of the mortality and selectivity coefficients. Differences between "total mortalities" from different samples are the result of different selectivities. In what follows, the term *total mortality* will sometimes be used to refer to the combined effect of total mortality and selectivity. If total mortality has not been constant or the selectivity pattern is not log-linear over the relevant age classes, this will cause process error in the statistical model.

3.2 Derivation of estimator

Let y_i denote the year of sampling for catch at age sample i,
let a_{min} be a minimum age,
let R denote mean recruitment (unknown constant not estimated),
let ζ_i denote the total mortality for sample i, assumed to be constant over age (to be estimated).

The expected number of fish of age a in sample i, will be proportional to $\rho_{y_i-a}Re^{-(a-a_{min})\zeta_i}$. Hence, the probability corresponding to age a in sample i,

$$\pi_{ia} = \frac{\rho_{y_i-a}\,e^{-(a-a_{min})\zeta_i}}{\sum_a \rho_{y_i-a}\,e^{-(a-a_{min})\zeta_i}}$$

where a takes values from a_{min} to whichever is the lesser of an overall maximum, a_{max}, and the age corresponding to the earliest available SST. Both α and R cancel from numerator and denominator. We need to estimate only β and $\{\zeta_i\}$. The $\{\zeta_i\}$ are largely nuisance parameters. The likelihood for sample i,

$$L_i = M_i!\prod_a \frac{\pi_{ia}^{M_i p_{ia}}}{(M_i p_{ia})!}$$

The negative of the logarithm of the likelihood for the set of samples, ignoring constant terms,

$$\Lambda = -\sum_i\sum_a M_i p_{ia}\log(\pi_{ia})$$

where the inner summation is over appropriate ages in each sample. The maximum likelihood estimators are then found by minimising Λ.

3.3 Diagnostics

The choice of the best SST proxies from those that satisfied the stationarity and consistency test and the choice of which months to use as predictors, was based on the value of Λ. We plotted scaled residuals against age to ensure there were no patterns that might indicate process error. The scaled residual for age a in sample i is

$$r_{ia} = \frac{p_{ia} - \pi_{ia}}{\sqrt{\dfrac{\pi_{ia}(1-\pi_{ia})}{M_i}}}$$

These plots were also used to determine the age at which full recruitment could be assumed, a_{min}.

Quantile plots were used to examine whether the data were consistent with the assumption of multinomial variability. For each age, a, and sample, i, the probability of obtaining a proportion no greater than the observed proportion was calculated,

$$Q_{ia} = \mathrm{F}(M_i p_{ia} : M_i, \pi_{ia})$$

where F() is the binomial distribution function with parameters sample size (M_i) and probability (π_{ia}). If F() were a continuous function a large sample of Q_{ia} values would be distributed approximately uniformly between 0 and 1. Because it is a discrete distribution, the Q_{ia} values would not be distributed uniformly between 0 and 1, but rather would have discrete steps at each integer quantile. To create an approximately uniform distribution we randomly select a probability for each p_{ia}, that lies between $\mathrm{F}(M_i p_{ia} : M_i, \pi_{ia})$ and $\mathrm{F}(M_i p_{ia} - 1 : M_i, \pi_{ia})$,

$$Q'_{ia} = U_{ia} \times \mathrm{F}(M_i p_{ia} : M_i, \pi_{ia}) + (1 - U_{ia}) \times \mathrm{F}(M_i p_{ia} - 1 : M_i, \pi_{ia}),$$

where U_{ia} is a random deviate between 0 and 1. We plotted the sorted Q'_{ia}s against a set of uniformly increasing probabilities between 0 and 1. True multinomial observations would be expected to lie along the 45° line between 0 and 1.

4. RESULTS

4.1 Examination of sea surface temperature data

The results suggested that SST profiles were similar for all the areas examined, with some variation in absolute values from different areas. Correlation coefficients were high (0.71–0.99) for all pairs of areas, including comparisons of Tasman-Golden Bay with the east coast areas (Table 2), but declined with the degree of spatial separation. Plots of absolute values showed similar patterns of fluctuation, but with differences between absolute values from different areas (Figure 3). Cumulative sum plots showed some variation in the low frequency, diagnostic fluctuation (Figure 4), but generally datasets for Areas 7 and 8 remained close to the long term mean. Comparative cumulative sum plots indicated consistency between the areas (Figure 5), although the high sensitivity of this technique suggested that temperature patterns in Area 7 differed slightly from those in Areas 1 and 8. We chose Areas 7 and 8 to represent the SST that would be most likely to influence recruitment to SNA 2 and SNA 7, since these were geographically the closest area and because they were otherwise satisfactory.

4.2 Examination of air temperature data

Examination of the aggregated datasets (from weather stations where their names/sites had changed) was aided by including a vertical line in the plots at the point where datasets were "spliced" together (see plots for Nelson Aero, Appleby, and Blenheim Research in Figure 6). There was no evidence at these points of any marked changes to the overall low frequency pattern that was largely common to all datasets.

Cumulative sum plots used for EDA of the air temperature series showed some variations in the low frequency, diagnostic fluctuation (Figure 6), but the main features of these patterns were similar in all the datasets. Cumulative sum comparative plots showed a close relationship between Napier-Nelson Park and Waipukurau Aero (Figure 7), Napier-Nelson Park and Kelburn, and between Appleby and Kelburn, suggesting a strong similarity between these weather stations and a widespread similarity in air temperature. By contrast, comparisons of Appleby with Nelson Aero and Blenheim Research showed systematic differences, perhaps as a result of localised temperature patterns or local environmental changes.

Comparisons of absolute temperature values (Figure 8) for Napier-Nelson Park with Wapukurau and with Kelburn reinforced the close relationship in their patterns, but showed a difference in absolute temperature between these stations. Data from the South Island showed closer relationships in absolute values, but as with the cumulative sum analysis, systematic deviations were evident for Nelson Aero and Blenhheim Research compared with Appleby and Kelburn. Appleby was markedly similar to Kelburn in both absolute temperature scale and pattern of fluctuation. Two main inconsistencies were evident.

- Two of the South Island datasets (Nelson Aero and Blenheim Research) showed systematic differences from the patterns exhibited by all the other stations.

- The Waipukurau data were quite similar to those of Napier-Nelson Park except for a slight difference towards the end of the period.

Based on these results, we concluded that air temperature data from Napier-Nelson Park and Appleby showed the least potential for bias.

4.3 Use of air temperature as a proxy for SST

The correlation coefficients between Napier-Nelson Park and Area 7, and between Appleby and Area 8 were 0.531 and 0.586 respectively. The cumulative sum plots indicated that Napier-Nelson Park showed a reasonably constant relationship with Area 7 between 1982 and 2000 (Figure 5), and that the relationship between Appleby and Area 8 was even more similar over the same period. Comparison plots of the absolute values (see Figure 6) further supported these relationships, with a particularly close relationship again evident for Appleby and Area 8. Based on these results and the evidence for the least systematic bias in their data, we concluded that air temperature data recorded at Napier-Nelson Park and Appleby were good proxies for remote sensing SST recorded from Areas 7 and 8 respectively.

4.4 Examination of recent catch at age data

As a result of some otoliths being re-read, the new proportion at age distributions for Tasman-Golden Bay and SNA 2 in 1997–98 and 1998–99 differ quite markedly from earlier distributions published by Blackwell et al. (1999, 2000). The revised distributions are shown in Figure 9 (values are given in Appendix 1). For SNA 2, 1997–98, re-reading of otoliths resulted in a reallocation of 6 year olds into the 7 year old category, thus reducing the size of the 1992 age class and strengthening that of 1991. For Tasman-Golden Bay, 1997–98, re-reading of otoliths resulted in a reallocation of 5 year olds into the 4 year old category, thus reducing the size of the 1993 age class and strengthening that of 1994. For SNA 2, 1998–99, the main result of re-reading otoliths was the disappearance of the 1997 age class. There was also some redistribution in the 6–8 year olds, causing a peak in the 1992 year class (7 year olds). This peak previously occurred in the 1993 age class. For Tasman-Golden Bay, 1998–99, re-reading the otoliths caused a swapping in the relative strengths of the 1995 and 1996 year classes, resulting in the revised distribution showing a dominance of the 1995 year class (4 year old fish).

Summary. The SNA 2 distributions show some consistency in the 1980–91 year classes, but the 20+ age class and those after 1991 appear inconsistent. The Tasman-Golden Bay distributions are reasonably consistent for year classes before 1993. Both areas show age classes 3–6 years unexpectedly strong in the 1998–99 samples. It is possible that warm temperatures in 1998 and 1999 (see Figure 3) caused these age classes to grow faster and recruit earlier than usual.

4.5 SNA 2 estimates

We obtained the best model fit (base case) with minimum age = 7 and for the 6-month mean Napier-Nelson Park air temperature from September to February (Table 3). Only 3-month and 6-month means were tried. The negative log-likelihood for the fit without the temperature term was significantly higher (Table 3). The fits to the data, with and without the temperature term, are shown in Figure 10. The negative log-likelihood increased as the minimum age was changed from 7 (Table 3) and as the start of the 6-month period was changed from September (Figure 11).

The estimated slope of the temperature recruitment relationship, $\beta = 0.508$ (Table 3), is similar to that estimated within the Hauraki Gulf/Bay of Plenty stock assessment model $\beta = 0.534$ (February–June) Gilbert et al. (2000), but higher than that estimated for SNA 8 $\beta = 0.296$ (December–January) Davies & McKenzie (2001).

4.6 SNA 2 diagnostics

The base case residuals showed a satisfactory pattern when plotted against age (Figure 12). The quantile plot for the base case was also satisfactory (Figure 13), although there was a large proportion of zero observations. Both Waipukurau and Kelburn temperatures gave very similar likelihoods and estimates of β to those of Napier-Nelson Park.

4.7 SNA 7 estimates

As for SNA 2, we obtained the most satisfactory model fit (base case) with minimum age = 7 and for the 6-month mean air temperature from September to February (Table 3). The negative log-likelihood for the fit without the temperature term was significantly higher (Table 3). The fits to the data, with and without the temperature term, are shown in Figure 14. The negative log-likelihood increased as the minimum age changed from 7 (Table 3) although a slightly smaller value occurred at minimum age 5. Residual diagnostics (see below) caused us to reject the minimum age = 5 model fit. Again September gave the best fit based on 6-month mean temperatures (see Figure 11).

The estimated slope of the temperature recruitment relationship, $\beta = 0.651$ (Table 3), is similar to those obtained previously for SNA 7, $\beta = 0.676$ (December–February) Annala & Sullivan (1996), and $\beta = 0.70$ (model 7, December–February) Harley & Gilbert (2000).

4.8 SNA 7 diagnostics

Residuals from the fit for minimum age = 5 showed that the model tended to overestimate the proportion of 5-, 6-, and 7-year-olds (Figure 12). This implies that on average these age classes were not fully recruited. The plot of residuals v age was more satisfactory for minimum age = 7, which corresponds to the lowest negative log likelihood (apart from minimum age = 5). We chose this as the base case for this reason, even though the 7-year-olds appeared not to be fully recruited.

The quantile plot for the base case model appeared satisfactory (Figure 13). There is quite a large proportion of zero age classes in these data also. When separate plots were made for fish up to and greater than 15 yr it was apparent that the multinomial model was not entirely satisfactory. Amongst the younger age classes there were too many very large and very small observations. The population (commercial and research catch) appeared to be more heterogeneous than our effective sample sizes allowed for. The fault may lie with the method used to obtain effective sample size from the stratified random samples and possible errors in the c.v.s used to obtain them (especially for samples S14, S15, and S29). It is unlikely that these deficiencies would substantially affect our estimates of β.

5. CONCLUSIONS

Year class strength in both the SNA 2 and Tasman-Golden Bay snapper stocks showed a positive relationship to spring–summer temperature. We estimated relationships with air temperature (at Napier-Nelson Park and Appleby) because time series start earlier than those for available SST. Local SST may in principle be a slightly better predictor, but since air temperature is highly correlated with it, air temperature is a good proxy. The slopes of the relationships were similar to those previously estimated for SNA 7 and that estimated for Hauraki Gulf/Bay of Plenty snapper. The period that gave the best predictor for both SNA 2 and Tasman-Golden Bay snapper was September–February, which is six months earlier than the best prediction period for Hauraki Gulf-Bay of Plenty and straddles that for SNA 8 (December–January). It is not clear whether these differences were caused by these stocks having different critical periods. A possible explanation is that any part of the whole spring to autumn period can affect year class strength and that the precise period that provides the best fit to a particular dataset is largely a matter of chance. What is clear is that recruitment to all New Zealand snapper stocks is positively related to SST.

For both stocks, temperature appeared to be a less precise predictor of year class strength than for Hauraki Gulf-Bay of Plenty (see Figures 10 and 14). Considerable lack of fit was apparent. Part of this was sampling error. It was only the process error that caused a lack of precision in the predictor but it is difficult to separate process error from sampling error. The lack of fit to the larger samples suggests that process error is large.

We suggest that when modelling SNA 2 and SNA 7 populations, it would be best to estimate year class strength parameters directly for the year classes for which adequate data are available, but for the others SST predictors should be used. These predictors will, on average, do considerably better than would be done by assuming mean recruitment.

6. DATA STORAGE

A generalised version of the datasets used in this work has been supplied to the NIWA Fisheries Data Manager for archive on CD under the project code SNA9805. No electronic data were generated for inclusion in any Schedule 3 database.

The new readings and ages for SNA 2, 1997–98 and 1998–99 have been entered into the age database.

7. ACKNOWLEDGMENTS

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Table 1: Background information on age samples used in the analysis by Fishstock from which the sample was collected.

Fishstock	Sample name	Source	Sample type	Estimated total mortality	Effective sample size	Actual sample size
SNA 2	S1, 1992	Comm. (9 landings)	SRS	0.268	29	145
	S2, 1998	Comm. (45 landings)	Stratified	0.321	159.3	1509
	S3, 1999	Comm. (34 landings)	Stratified	0.210	249.4	930
SNA 7	S1, 1969	Res. (1 voyage)	SRS	0.009	24.8	124
	S2, 1970	Comm. (1 landing)	SRS	0.033	8	40
	S3, 1971	Res. (1 voyage)	SRS	-0.001	40	200
	S4, 1971	Res. (1 voyage)	SRS	0.060	25.6	128
	S5, 1971	Res. (1 voyage)	SRS	0.014	26.4	132
	S6, 1971	Res. (1 voyage)	SRS	0	12.2	61
	S7, 1971	Res. (1 voyage)	SRS	0.027	15	75
	S8, 1972	PT (1 landing)	SRS	0.004	19	95
	S9, 1974	Comm. ST (1 landing)	SRS	0.048	20.8	104
	S10, 1974	Comm. ST (1 landing)	SRS	0.071	16.6	83
	S11, 1974	Comm. ST (1 landing)	SRS	0.081	36.2	181
	S12, 1974	Comm. ST (1 landing)	SRS	0.102	33.4	167
	S13, 1974	Comm. ST (1 landing)	SRS	0.067	20.8	104
	S14, 1974	Comm. ST (1 landing)	Stratified	0.067	308.1	109
	S15, 1974	Comm. ST (1 landing)	Stratified	0.236	205.6	97
	S16, 1978	Comm. PT (1 landing)	SRS	0.068	17.8	89
	S17, 1978	Comm. PS (1 landing)	SRS	0.094	19.8	99
	S18, 1978	Comm. PT (1 landing)	SRS	0.092	10.6	53
	S19, 1978	Comm. PT (1 landing)	SRS	0.062	10.6	53
	S20, 1978	Comm. PT (1 landing)	SRS	0.107	15.6	78
	S21, 1979	Comm. PT (1 landing)	SRS	0.162	16.8	84
	S22, 1980	Comm. ST (1 landing)	SRS	0.196	9.8	49
	S23, 1980	Comm. PT (1 landing)	SRS	0.163	20.8	104
	S24, 1980	Comm. PS (1 landing)	SRS	0.081	30.2	151
	S25, 1980	Comm. PT (1 landing)	SRS	0.077	8.4	42
	S26, 1984	Comm. PT (1 landing)	SRS	0.148	36.2	181
	S27, 1984	Comm. PT (1 landing)	SRS	0.158	17	85
	S28, 1987	Res. (Tag programme)	Stratified	0.264	173.5	508
	S29, 1993	Comm. ST (33 landings)	Scaled ALK	0.184	741.2	364
	S30, 1998	Comm. (47 landings)	Stratified	0.162	301.4	1439
	S31, 1999	Comm. (35 landings)	Stratified	0.168	448.7	913

Comm. is commercial — Res. is research trawl (trawl survey) — PT is pair trawl
ST is single trawl — PS is purse-seine — SRS is stratified random sample
Stratified is stratified sample — ALK is length frequency converted to age via age-length key

Table 2: Correlation coefficients from pair-wise comparisons of the sea surface temperature (SST) datasets from six areas from East Cape to the Wairarapa coast and Tasman-Golden Bay (see text for definitions); Area 6 data were not comparable because of the high proportion of land and were excluded.

	Area 2	Area 3	Area 4	Area 5	Area 7	Area 8
Area 1	0.9732	0.9311	0.8554	0.9129	0.7487	0.7125
Area 2		0.9824	0.9318	0.9761	0.8376	0.7743
Area 3			0.9427	0.9859	0.8815	0.7960
Area 4				0.9812	0.9510	0.8216
Area 5					0.9190	0.8178
Area 7						0.8256

Table 3: Negative log likelihood values and values of the temperature term (β) for model runs under differing conditions of air temperature data (weather station), period of interest, minimum age, start month (1 is January), and with β either constrained to zero or estimated by the model. The base case is shaded grey for each Fishstock and is defined as the model run selected as the best fit given the resulting negative log likelihood value and information on the air temperature dataset determined during exploratory data analysis.

Fishstock	Weather station	Period (months)	Minimum age	Status of β	Start month	Negative log likelihood	β
SNA 2	Napier-Nelson Park	6	7	Estimated	-5	1029.83	0.321
	Napier-Nelson Park	6	7	Estimated	-4	1026.18	0.416
	Napier-Nelson Park	6	7	Estimated	-3	1021.56	0.508
	Napier-Nelson Park	6	7	Estimated	-2	1023.09	0.425
	Napier-Nelson Park	6	7	Estimated	-1	1026.77	0.295
	Napier-Nelson Park	6	7	Estimated	0	1026.02	0.285
	Napier-Nelson Park	6	7	Estimated	1	1027.29	0.268
	Napier-Nelson Park	6	7	Estimated	2	1029.25	0.233
	Napier-Nelson Park	6	7	Set to 0	-3	1033.08	0
	Napier-Nelson Park	6	5	Estimated	-3	1076.29	0.484
	Napier-Nelson Park	6	6	Estimated	-3	1036.17	0.332
	Napier-Nelson Park	6	8	Estimated	-3	1030.55	0.647
	Napier-Nelson Park	6	9	Estimated	-3	1033.60	0.870
	Waipukurau	6	7	Estimated	-3	1021.56	0.511
	Kelburn	6	7	Estimated	-3	1021.68	0.507
	Napier-Nelson Park	3	7	Estimated	-3	2084.39	0.724
SNA 7	Appleby	6	7	Estimated	-5	7787.65	0.567
	Appleby	6	7	Estimated	-4	7741.69	0.600
	Appleby	6	7	Estimated	-3	7696.02	0.651
	Appleby	6	7	Estimated	-2	7749.53	0.533
	Appleby	6	7	Estimated	-1	7729.44	0.541
	Appleby	6	7	Estimated	0	7729.41	0.520
	Appleby	6	7	Estimated	1	7785.28	0.485
	Appleby	6	7	Estimated	2	7867.09	0.288
	Appleby	6	7	Set to 0	-3	7872.56	0
	Appleby	6	5	Estimated	-3	7671.31	0.673
	Appleby	6	6	Estimated	-3	7735.02	0.668
	Appleby	6	8	Estimated	-3	7856.54	0.454
	Appleby	6	9	Estimated	-3	7806.42	0.457
	Nelson Aero	6	7	Estimated	-3	7249.20	0.687
	Kelburn	6	7	Estimated	-3	7967.35	0.599
	Appleby	3	7	Estimated	-3	7806.72	0.460

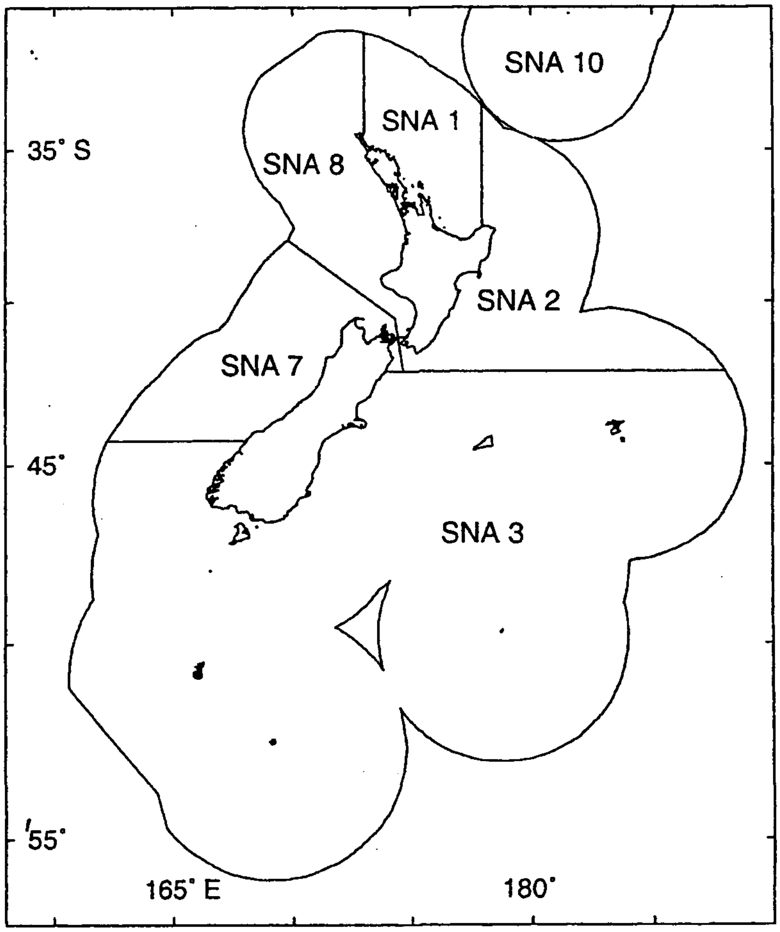

Figure 1: Snapper Fishstocks.

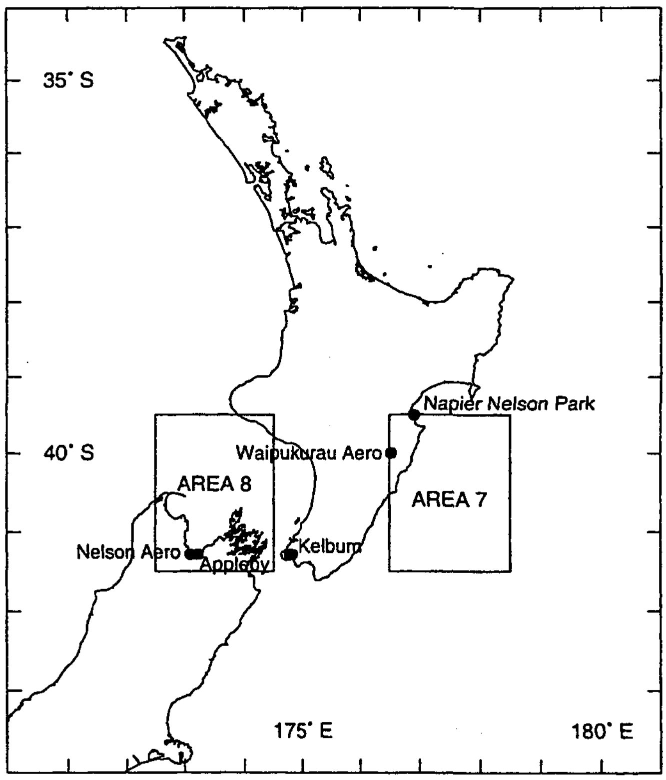

Figure 2: Locations of weather stations and Areas 7 and 8 (2 ° x 2 ° squares) where air temperature and remote-sensing SST data (respectively) used in the analysis were recorded.

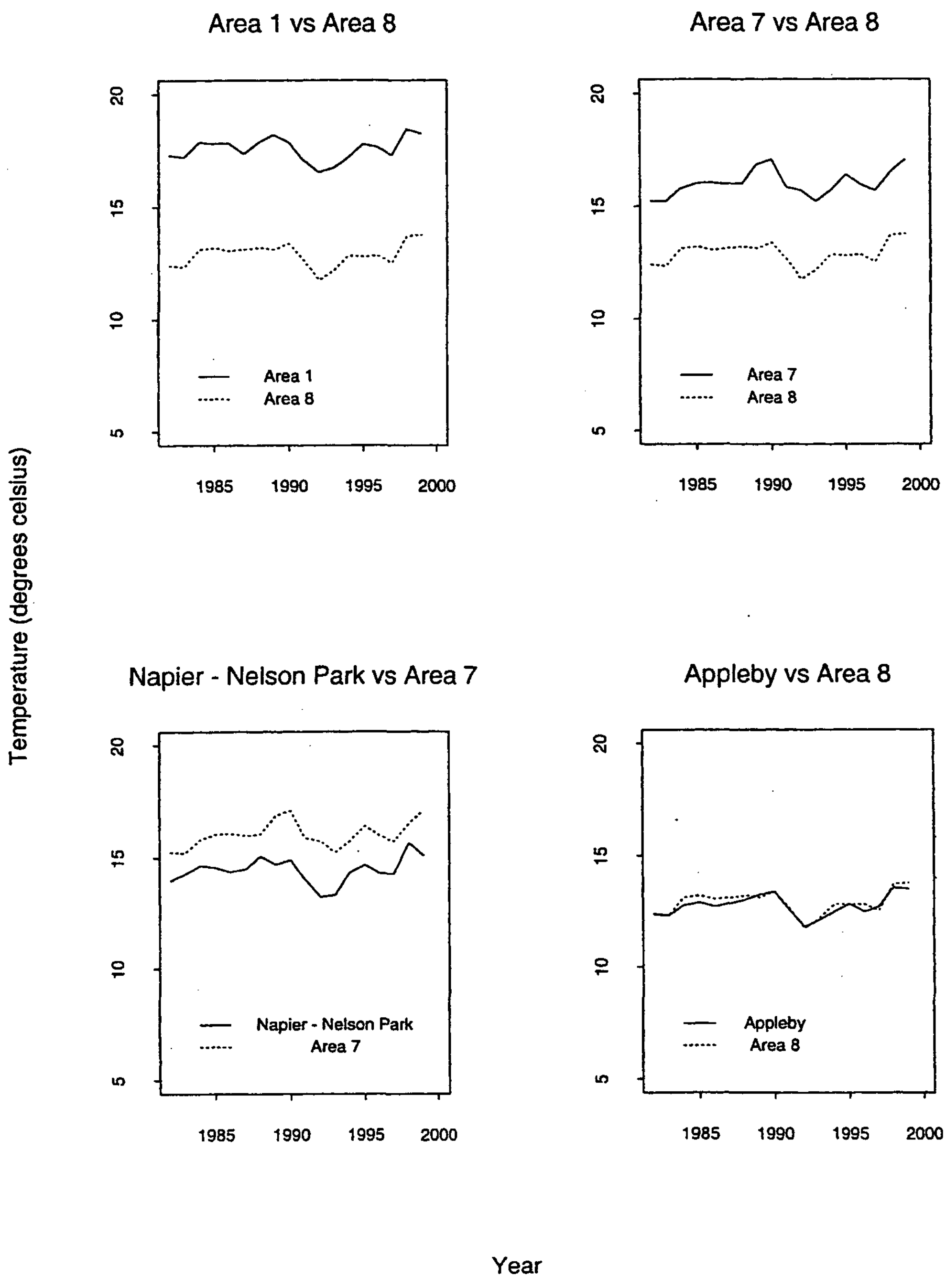

Figure 3: Comparative plots of absolute temperature values for the areas and weather stations where remote-sensing sea surface temperature and air temperature data were recorded (sources: NIWA climate database and United States National Weather Service's Climate Analysis Center).

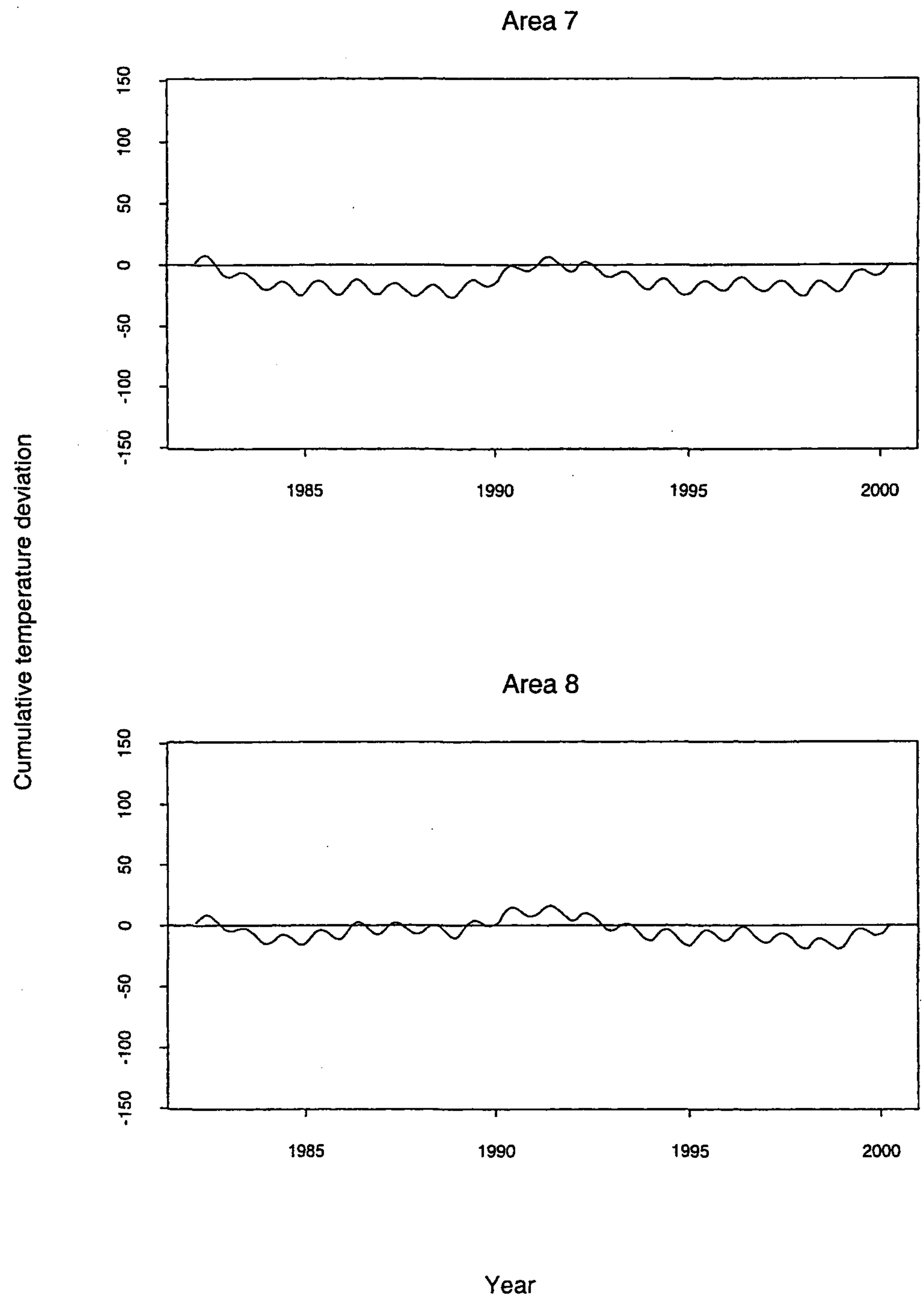

Figure 4: Cumulative sum plots for Areas 7 and 8, the 2 ° x 2 ° squares where remote-sensing sea surface temperature data used in the analysis were recorded (source: United States National Weather Service's Climate Analysis Center).

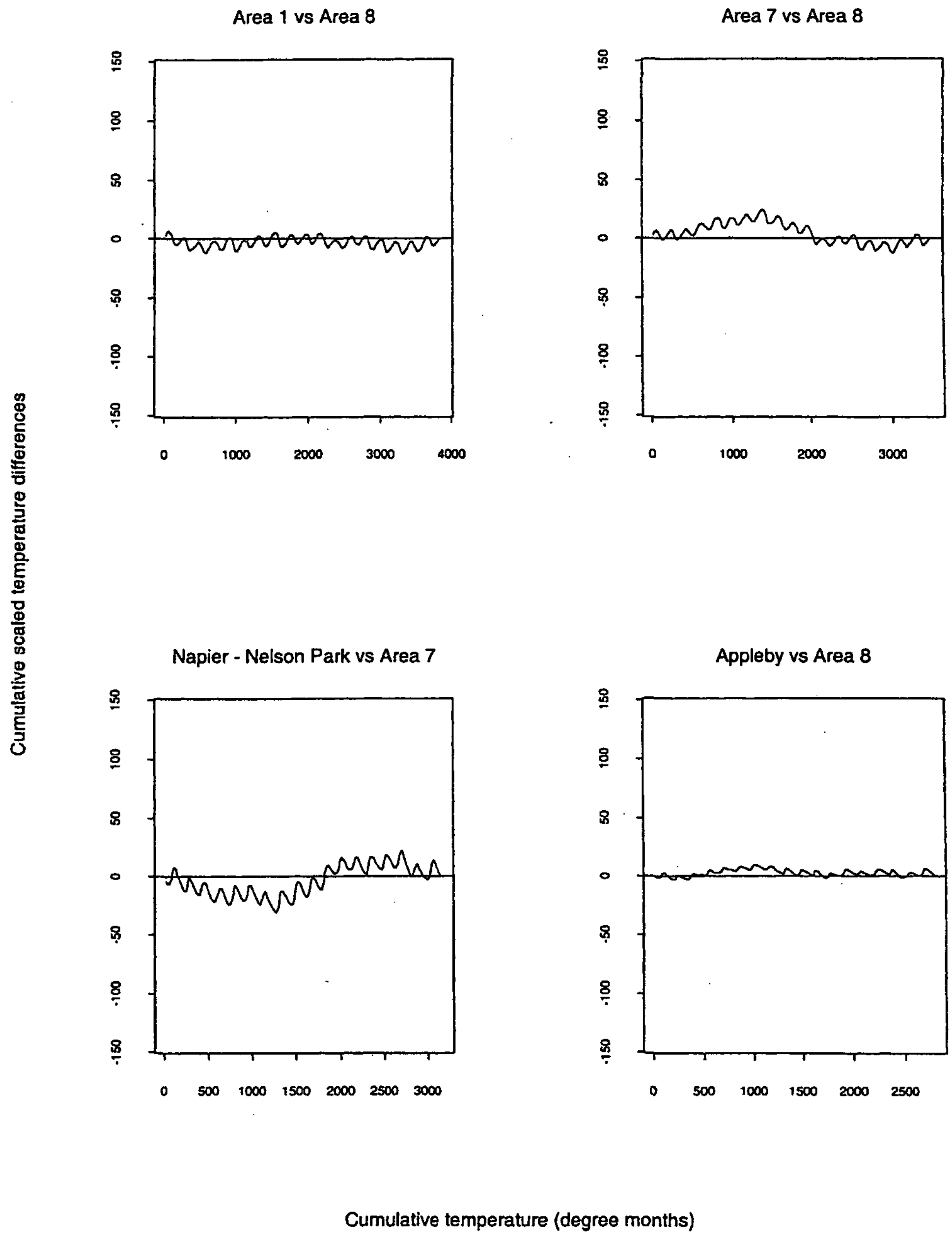

Figure 5: Cumulative sum comparative plots of areas and weather stations where remote-sensing sea surface temperature and air temperature data were recorded (sources: NIWA climate database and United States National Weather Service's Climate Analysis Center).

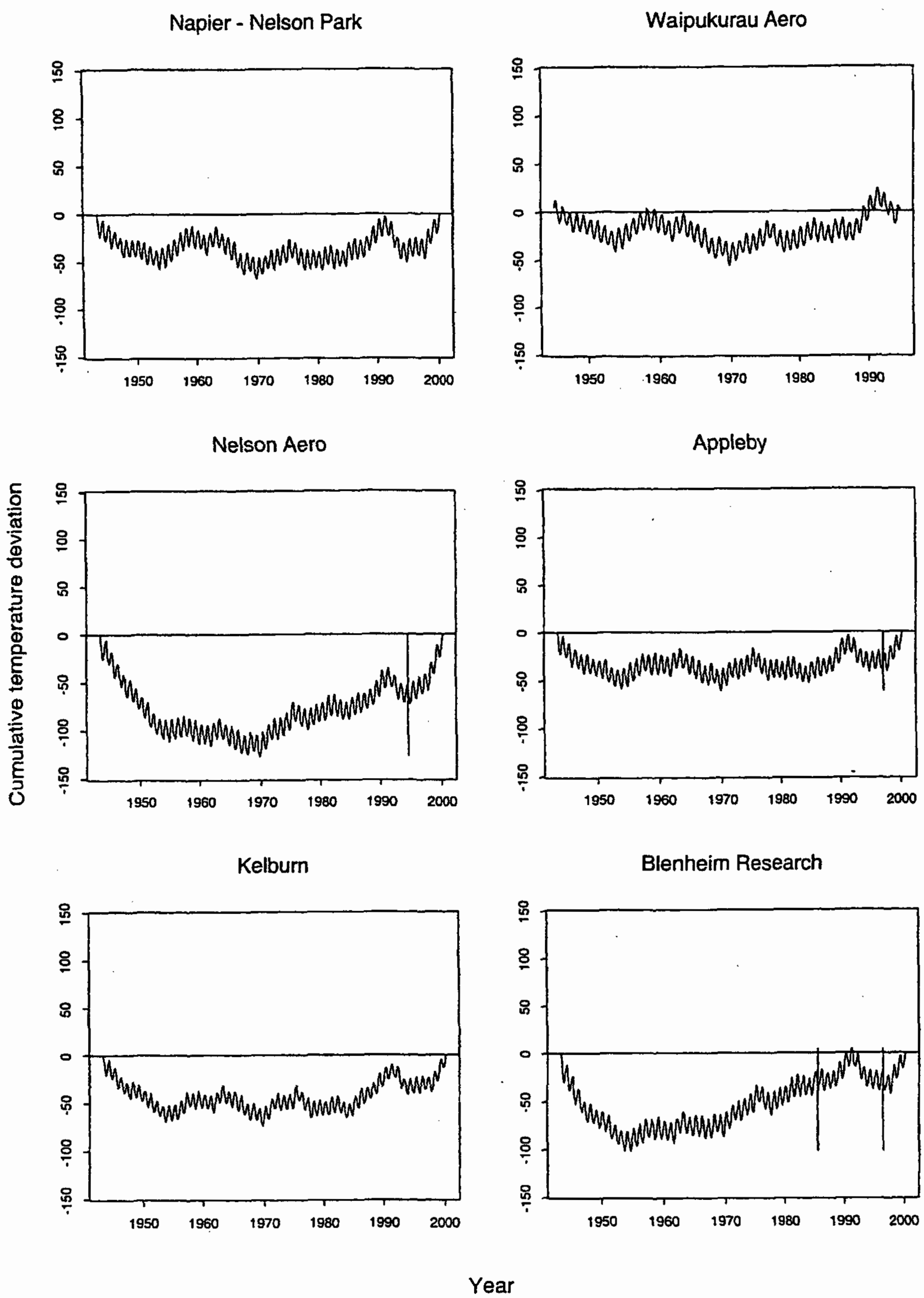

Figure 6: Cumulative sum plots of air temperature for the weather stations considered as sources of data for proxies of sea surface temperature data (source NIWA climate database).

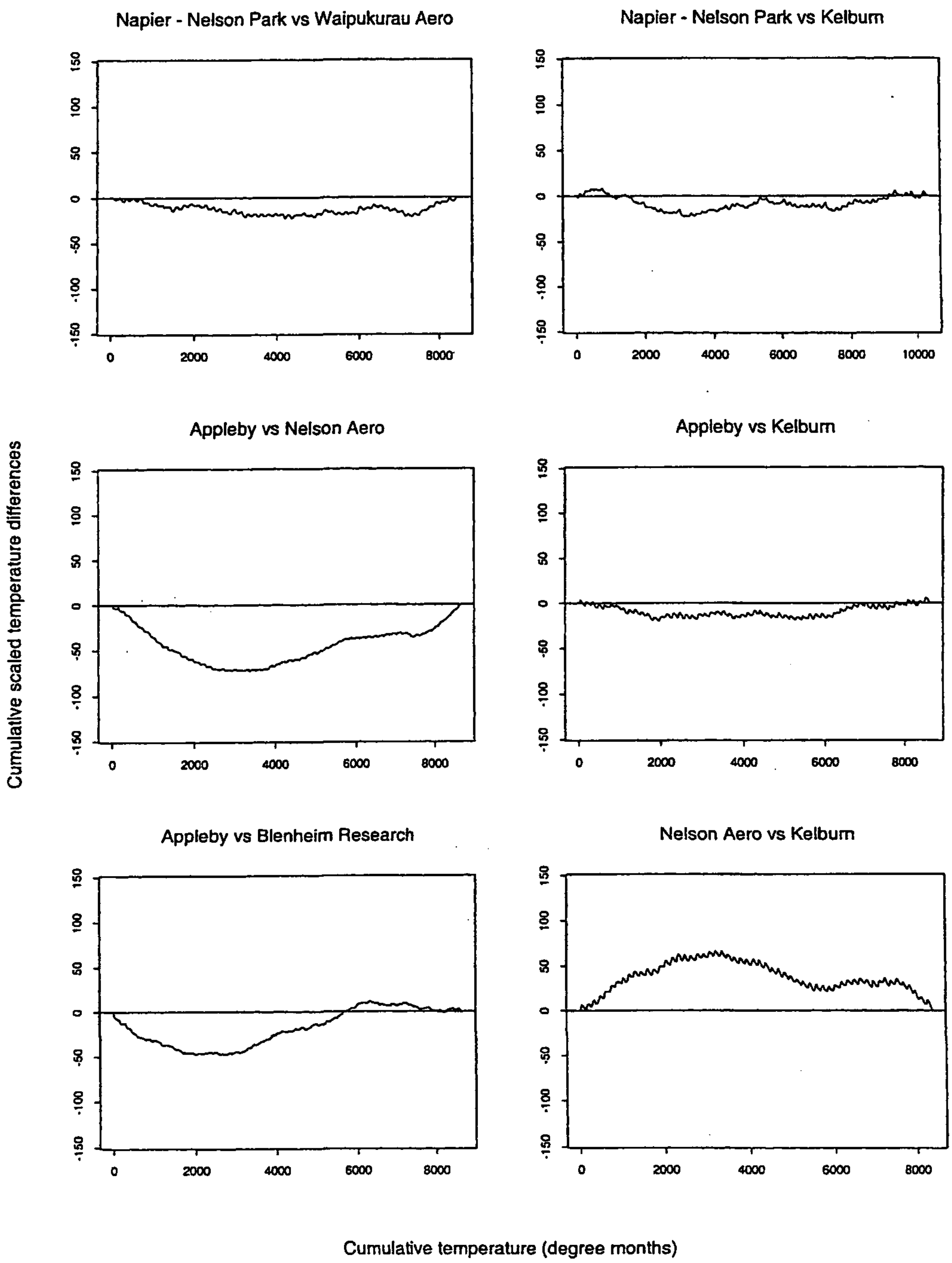

Figure 7: Cumulative sum comparative plots of weather stations considered as sources of data for proxies of sea surface temperature data (source: NIWA climate database).

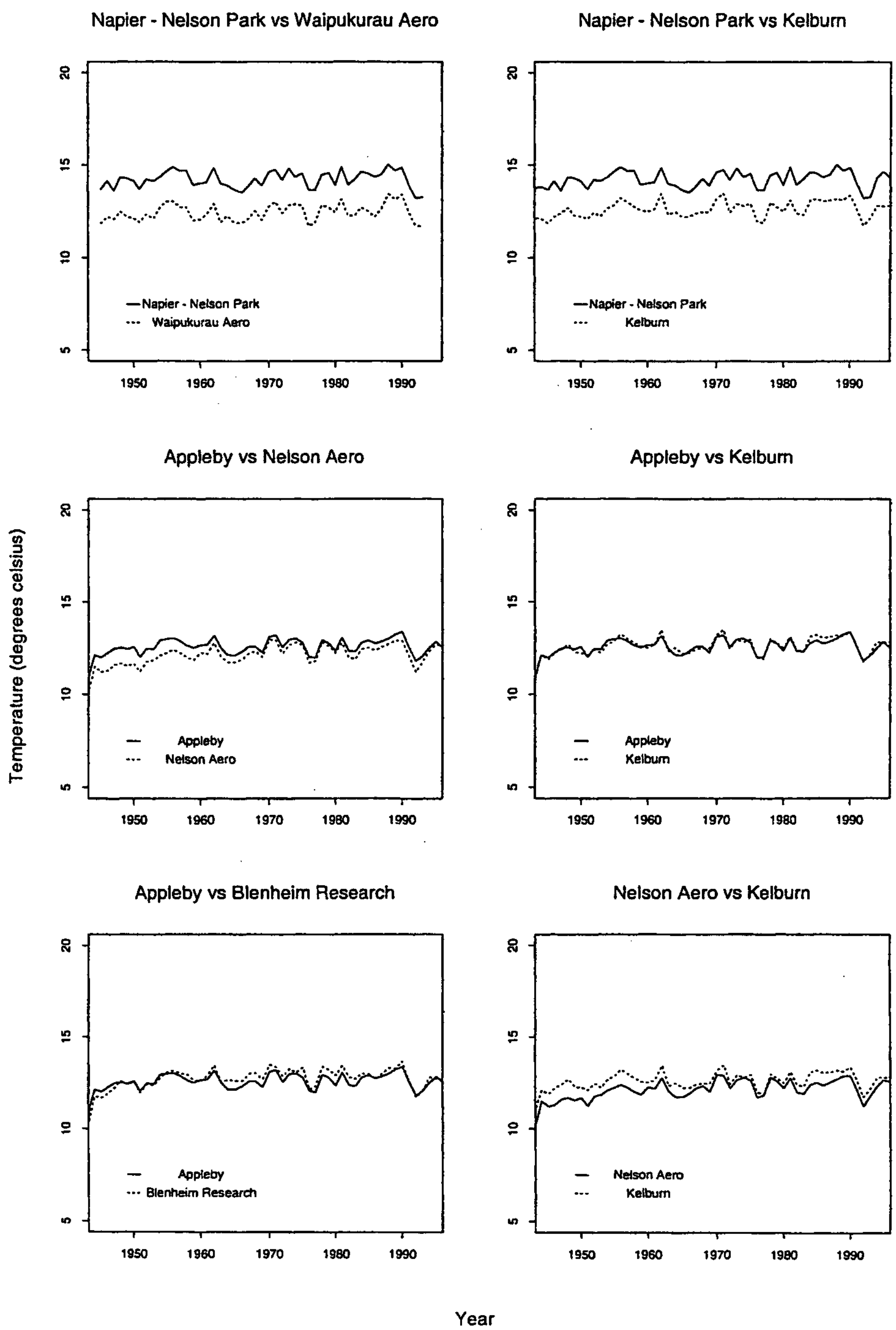

Figure 8: Comparisons of absolute values of air temperature data from the weather stations considered as sources of data for proxies of sea surface temperature data (source: NIWA climate database).

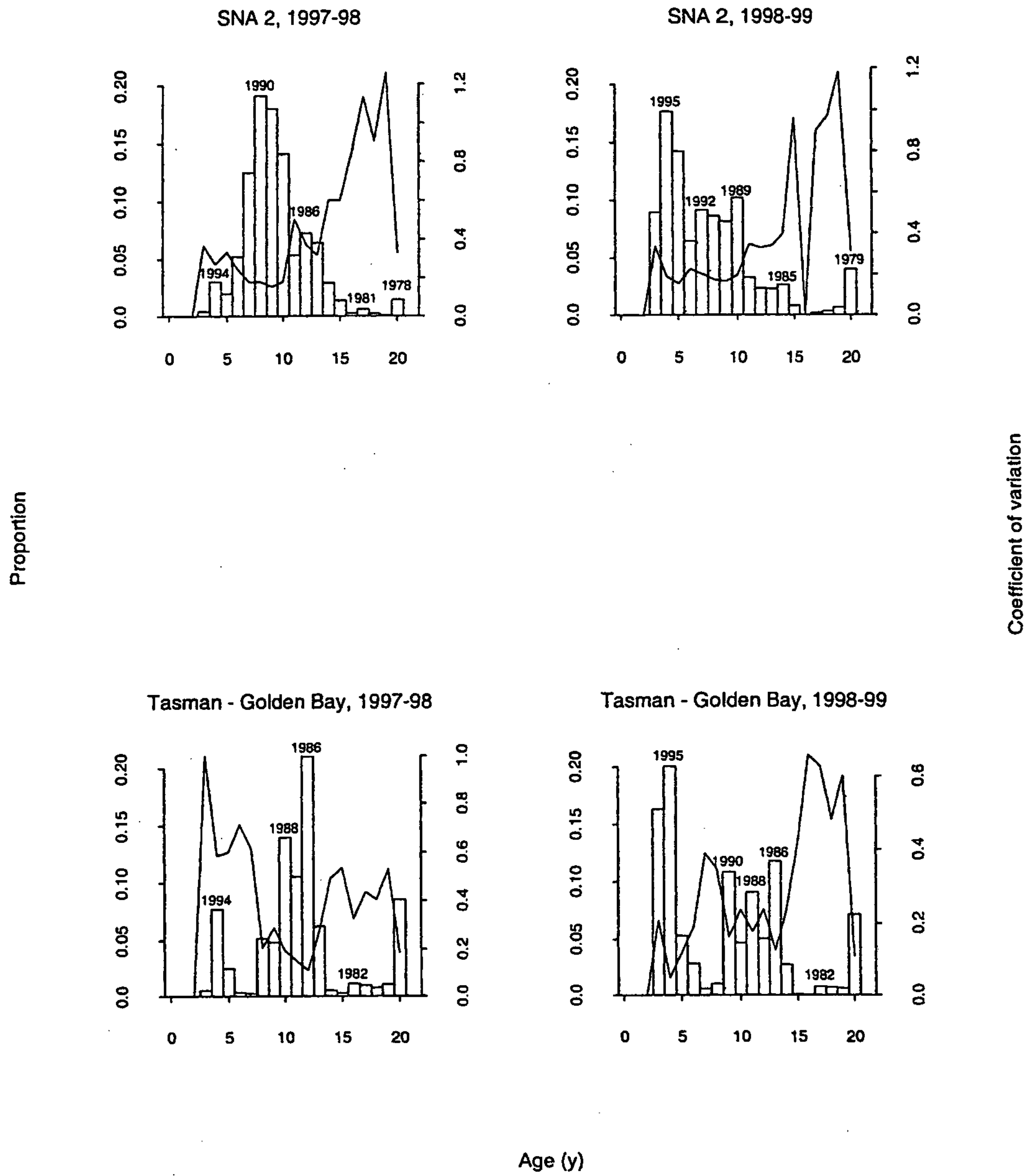

Figure 9: Revised proportion at age estimates (histogram) and c.v.s (line) for SNA 2 and Tasman-Golden Bay (SNA 7) landings in 1997–98 and 1998–99.

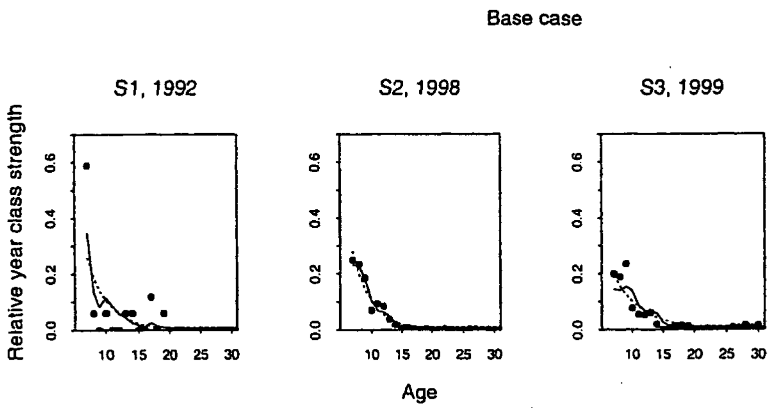

Figure 10: Fit to catch at age data for SNA 2; points are observed values, unbroken line shows the fitted values, and the broken line shows the fitted values where the temperature term is zero.

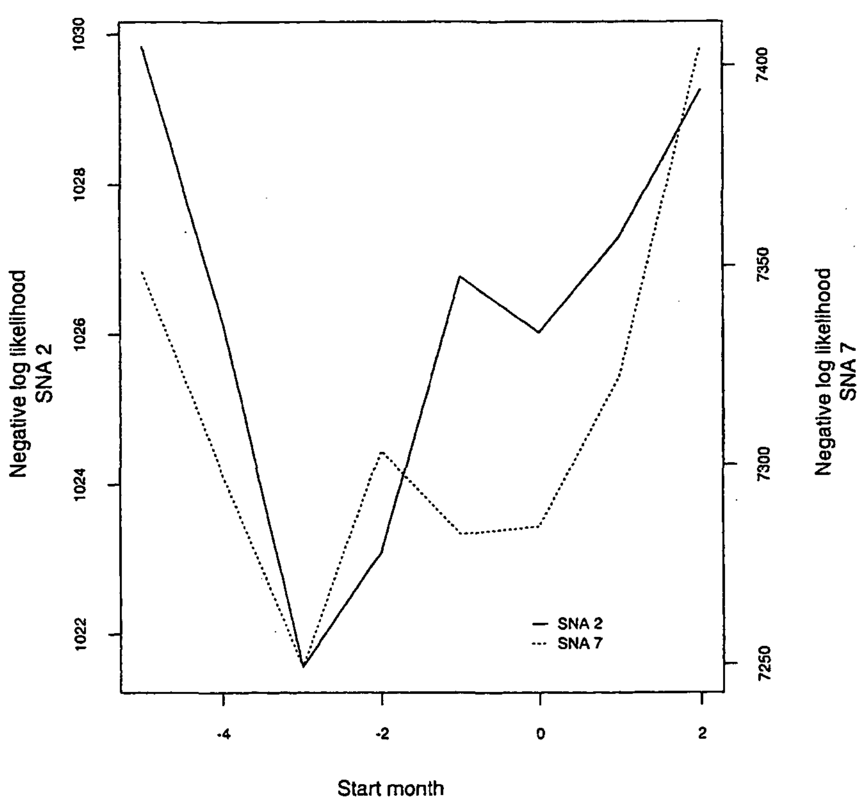

Figure 11: Change in the negative log likelihood with start month (January is 1, September is –3) or first month of the 6 months over which the catch at age data are fitted; for SNA 2 and Tasman-Golden Bay (SNA 7).

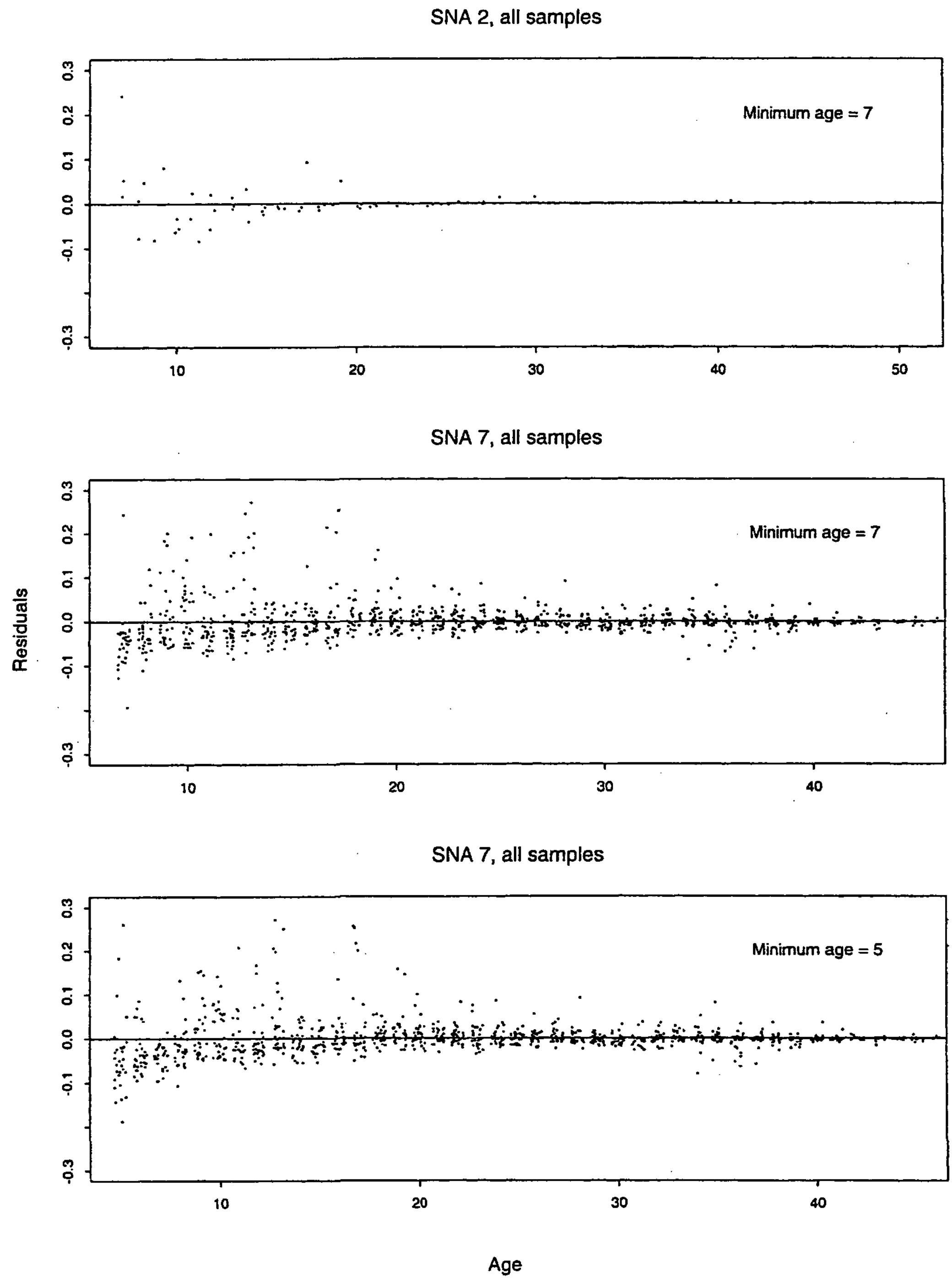

Figure 12: Residuals (jittered) from the model fit for SNA 2 and Tasman-Golden Bay (SNA 7).

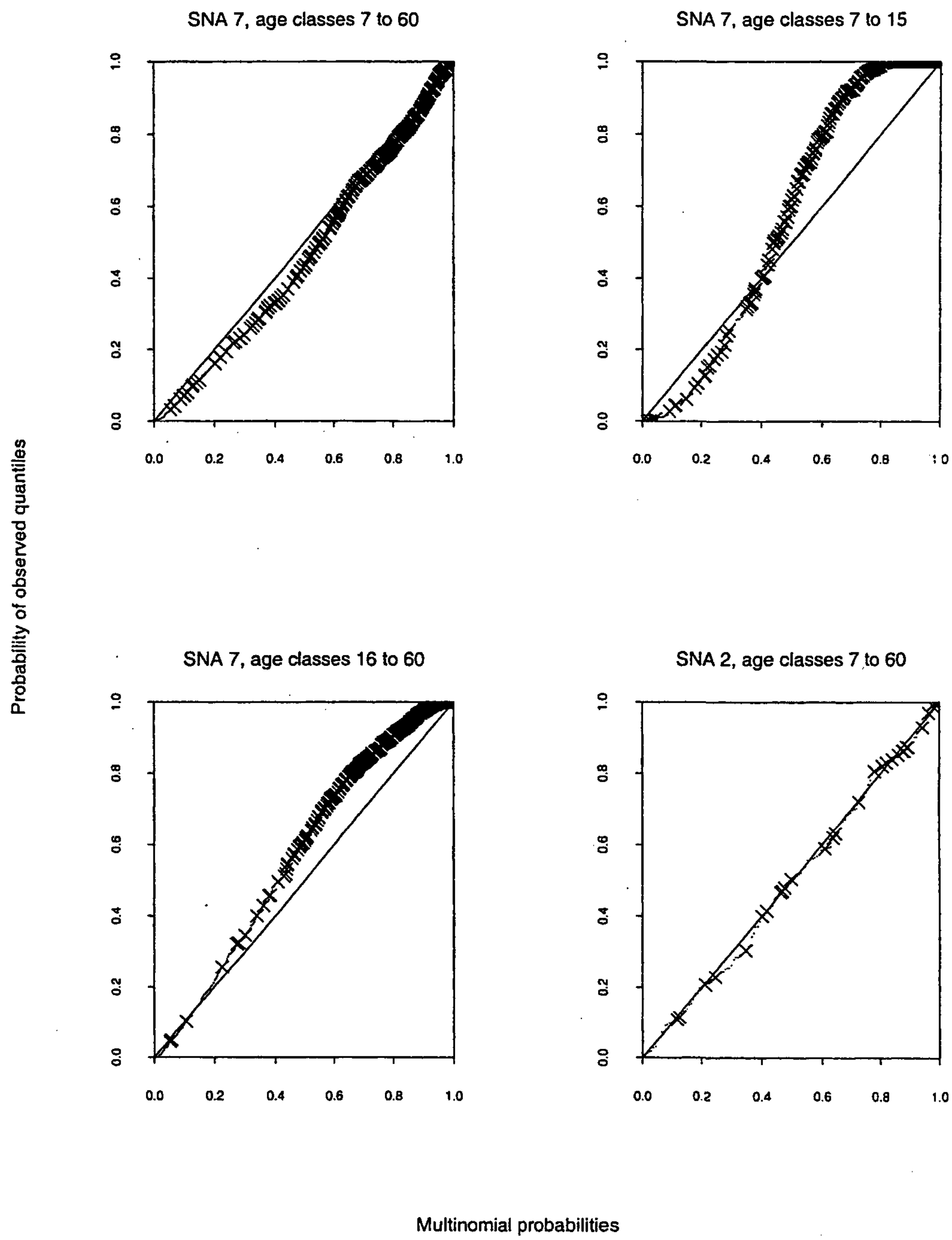

Figure 13: Quantile plots from the best model fits for SNA 2 and Tasman-Golden Bay (SNA 7) (zero observations are shown as "."); three variations of the SNA 7 quantile plot are shown: all year classes used in the best fit, year classes 7 to 15, and year classes 16 to 60.

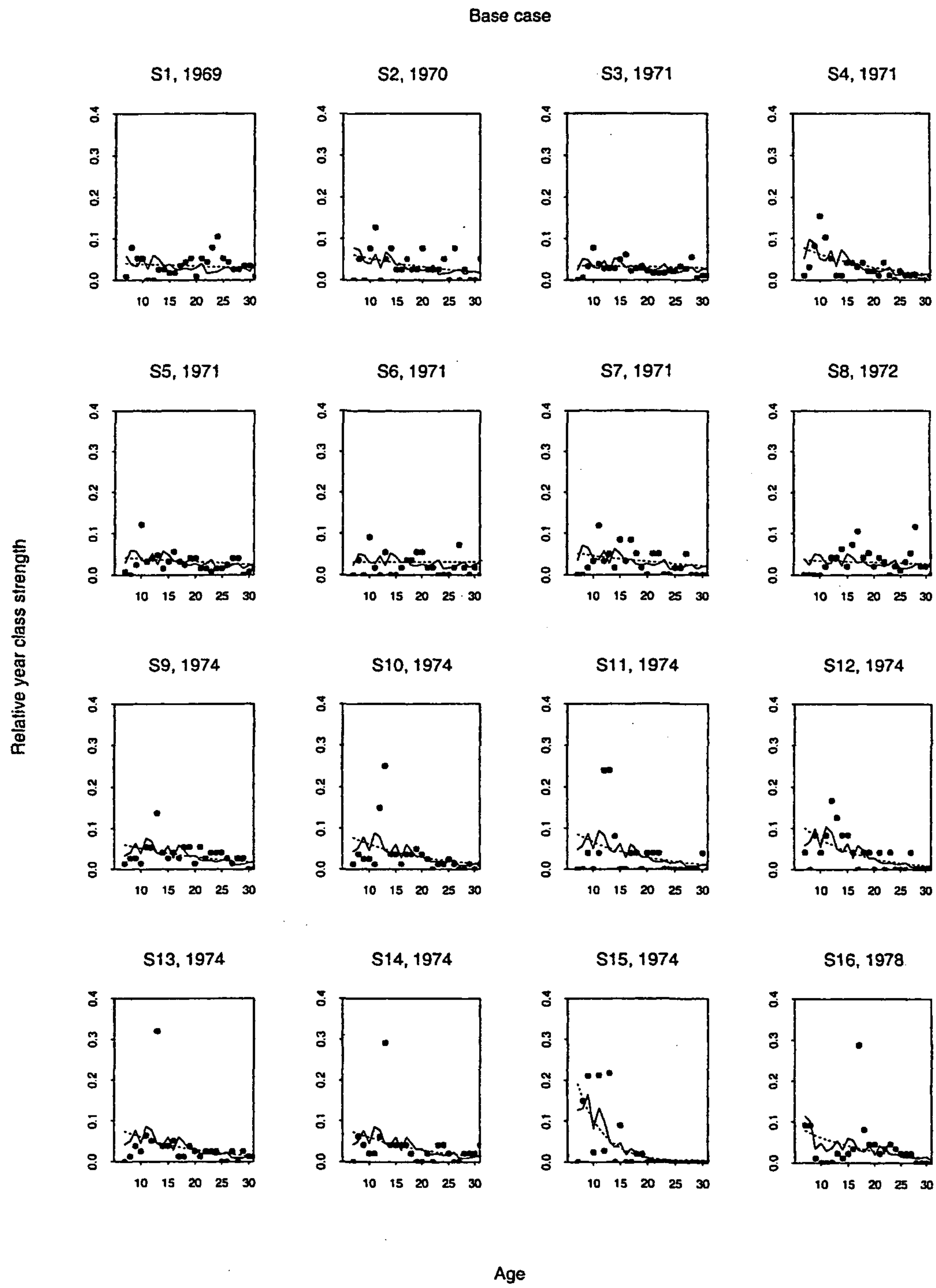

Figure 14: Fit to catch at age data for Tasman-Golden Bay (SNA 7); points are observed values, unbroken line shows the fitted values, and the broken line shows the fitted values where the temperature term (β) is zero.

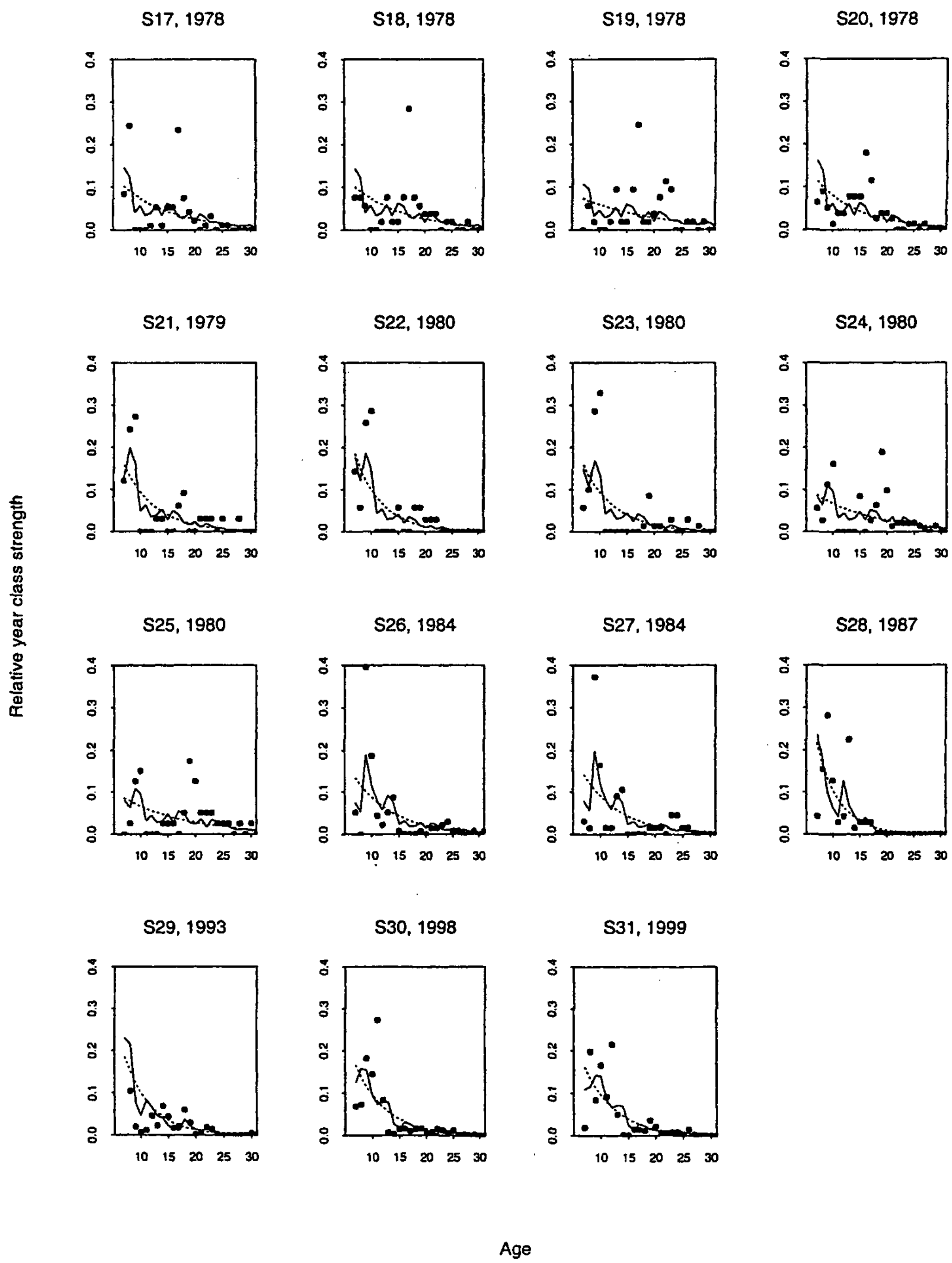

Figure 14: ***Continued.***

Appendix 1: Revised proportion at age estimates for SNA 2 and Tasman-Golden Bay (SNA 7) landings in 1997–98 and 1998–99

	SNA 2		Tasman-Golden Bay (SNA 7)	
Age class	1997–98	1998–99	1997–98	1998–99
1	0	0	3.72E-05	0
2	0	0	0	0.000184
3	0.00404	0.089421	0.005655	0.163049
4	0.030229	0.176935	0.07747	0.201134
5	0.019439	0.142077	0.024996	0.052639
6	0.051739	0.064422	0.003558	0.028218
7	0.12495	0.091512	0.005378	0.006387
8	0.191141	0.086302	0.060161	0.010638
9	0.180071	0.0817	0.064335	0.108878
10	0.140935	0.102228	0.159746	0.046513
11	0.053186	0.03281	0.127827	0.090864
12	0.072399	0.023373	0.240462	0.050445
13	0.063684	0.022779	0.073453	0.117905
14	0.028827	0.026423	0.006736	0.027386
15	0.013532	0.008057	0.002882	0.00114
16	0.002671	0	0.013566	0.000552
17	0.006337	0.002039	0.01408	0.008351
18	0.002251	0.003302	0.009465	0.007541
19	0.000279	0.006582	0.014002	0.006747
20	0.001732	0.005437	0.014851	0.020162
21	0.000202	0	0.005313	0.01206
22	0.00024	0.000545	0.007644	0.004039
23	0.001665	0.002192	0.013971	0.004105
24	0.000592	0.00087	0.010796	0.005273
25	0	0.000651	0.005101	0.004952
26	6.61E-05	0.000651	0.011087	0.001692
27	0.001448	0.00306	0.001405	0.008265
28	0.000653	0.002337	0.002224	0.002108
29	0	0.007325	0.00066	0.000481
30	0.00018	0.001541	0.002569	0
31	0	0.006582	0	0
32	0.000529	0	0.000397	0
33	0	0	0	0.000201
34	6.2E-05	0	0.001783	0
35	0.000128	0.000651	0.000782	0.000631
36	0.000529	0	0.003571	0.001317
37	0.000339	0	0.001322	0.002122
38	0.00024	0	0.002241	0.000982
39	0	0.001541	0.002241	0.000184
40	0	0.00087	0.000397	0.000802
41	0.002721	0.001561	0.004878	0
42	0.001505	0.002023	0.00025	0
43	0.000529	0	0.000928	0.001037
44	0.000185	0	0.000325	0
45	0	0	0.000247	0.000743
46	0	0.001541	0	0.00028
47	0	0	0	0

Appendix 1: ***Continued***

	SNA 2		Tasman-Golden Bay (SNA 7)	
Age class	1997–98	1998–99	1997–98	1998–99
48	0	0	0.000965	0
49	0.000639	0	0	0
50	0	0	0	0
51	6.2E-05	0.000664	0.00025	0
52	0	0	0	0
53	0	0	0	0
54	0	0	0	0
55	0	0	0	0
56	0	0	0	0
57	0	0	0	0
58	0	0	0	0
59	2.98E-05	0	0	0
60	0	0	0	0