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An examination of species proportion estimates, standardised stock indices, and the use of age-structured stock assessment models for jack mackerel, *Trachurus declivis* and *T. novaezelandiae*, in JMA 7

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1. EXECUTIVE SUMMARY

This report summarises a study determining the feasibility of developing age-structured stock assessment models for *Trachurus declivis* and *T. novaezelandiae* in JMA 7. A positive result overall was dependent on acceptable results from three major components in the methodology: reliable estimates of species proportions in the catch of the three *Trachurus* species, reliable estimates of relative abundance indices from the commercial trawl catch and effort data, and acceptable estimates of virgin biomass (B_0) and $F_{0.1}$ from an age-structured model.

The stock reduction model is used in this study as an example of an age-structured stock assessment model. In the present context it is a simplistic age-structured model that uses deterministic recruitment, but could include information on year class strength as age frequencies from the year-to-year catch become available. The feasibility of using age-structured models is investigated by working through the steps for producing estimates of B_0 and $F_{0.1}$ using the stock reduction model, and, subsequently, estimates of CAY and MCY.

Species proportions were estimated from tow samples of the trawl fleet in JMA 7 gathered by the Scientific Observer Programme since 1989 when the data are most reliable. Two time series of species proportions were required. For the CPUE estimates, proportions were based on data aggregated by quarter, which was chosen in preference to a shorter time frame to minimise the amount of interpolation required for replacement of missing values. For the catch history, annual proportions were produced from the observer data, and estimates based on a trawl survey by *Shinkai Maru* in 1981–82 were included for earlier years of the fishery.

Multiple linear modelling techniques were used to standardise the CPUE stock indices. Errors were assumed to be normal. Zero tows were included by adding a constant equal to 1% of the minimum non-zero value of the CPUE series. Explanatory variables were selected based on three steps: 22 variables, including 'year', were passed to an automated stepwise function which produced an initial model — p values were estimated from an analysis of variance; the selected explanatory variables were refitted using a linear modelling function to ensure a reliable result — only variables with significant p values (10^{-5} or less) were included; the variables were manually added in a stepwise fashion to determine the amount each added to the R^2 statistic — where no significant increase occurred the variables were discarded.

A total of 12 indices were standardised using this technique. Using the quarterly species proportions, the original CPUE series had been modified to provide three separate series for *T. declivis*, *T. novaezelandiae*, and *T. declivis* and *T. novaezelandiae* combined. Exploratory data analysis had suggested the possibility of two separate fisheries, one from November to April, the other from May to October, operating over different geographic ranges. The four CPUE series therefore provided three separate indices — one for all the data combined, and one each for the 'summer' and 'winter' fisheries. Indices from the unmodified CPUE series (all

three species), were included in the standardisation to examine whether there were any systematic differences between the way explanatory variables were included in the modified and unmodified series. Some differences were evident but difficult to interpret.

Estimates of annual relative abundance were estimated as year effects based on coefficients from the linear model. Estimates from the separate CPUE series for *T. declivis* and *T. novaezelandiae* for the summer and winter fisheries were input as stock indices to a stock reduction model which was employed to examine the feasibility of their use. The model was constructed in Microsoft Excel 97, and its operation was based on minimising the differences between the observed stock indices and a series of predicted indices estimated by the model. These differences were summarised as a sum of squares, and minimisation was achieved by iteration using the Excel 'solver' function; iterations were based on varying the values of virgin recruitment (R_0). Estimates of B_0 for each species were produced by the model.

The influence of several outliers was of concern following examination of residual plots from the predicted and observed stock indices. To minimise their effect, the model was rerun using a robust likelihood test statistic. Results from this approach suggested major influence of the outliers on the model fit, and examination of plots of observed and predicted stock indices showed that the fit was poor.

A yield per recruit analysis was constructed in Microsoft Excel 97 based on R_0 values for each species from the stock reduction model. Estimated *CAY* values were included in a routine to produce $F_{0.1}$ for each species. The B_0 and $F_{0.1}$ values from the Excel models were used to estimate *MCY*.

The critical point which prevents development of age-structured stock assessment models for *T. declivis* and *T. novaezelandiae* in JMA 7 is the unacceptably high level of variance in the estimates of species proportions from scientific observer data. There is also evidence from earlier work that most of *T. novaezelandiae* in JMA 7 is distributed within areas inaccessible to the observed fleet, suggesting that the scientific observer data may provide inadequate coverage of the spatial range of the jack mackerel population in JMA 7.

Because of the high level of uncertainty in the species proportions estimates, outputs from the stock reduction model and the yield per recruit analysis presented here cannot be used in management of the JMA 7 Fishstock.

2. INTRODUCTION

2.1 Overview

This document describes work completed under MFish funded project JMA9701 to determine the feasibility of developing age-structured stock assessment models for *Trachurus declivis* and *T. novaezelandiae* in JMA 7. Three steps were required to complete the work.

1. Determine the proportions of the three *Trachurus* species (*T. declivis*, *T. symmetricus murphyi*, *T. novaezelandiae*) in JMA 7.

2. Determine the feasibility of estimating separate relative abundance indices for *T. declivis* and *T. novaezelandiae* in JMA 7 from the commercial trawl fishery CPUE data for jack mackerel.
3. Determine the feasibility of developing the age-structured models.

Based on the results of this work, updates of stock assessments of *T. declivis* and *T. novaezelandiae* in JMA 7 are presented, including estimates of biomass and sustainable yields.

2.2 Description of the Fishery

The jack mackerel fishery in JMA 7 catches three species, the two "New Zealand species", *Trachurus declivis* and *T. novaezelandiae*, and the more recently arrived *T. symmetricus murphyi* (the Peruvian jack mackerel).

The fishery dates back to 1946 (Anon. 1947) but catches were low until the late 1960s (Table 1) when Japanese trawlers began fishing off Taranaki outside the 12 n. mile Territorial Sea. Exactly when this began is unclear, but information from the popular press (Berry 1969a, 1969b, 1972) suggests fishing by several Japanese trawlers beginning about 1967. More precise information is unavailable from MFish because New Zealand could not impose a requirement for catch records when fishing was outside the 12 n. mile limit.

From 1971 to 1978, activity in the fishery was predominantly Japanese, but the imposition of a 100 mm cod end mesh and the setting of a 5000 t quota after the EEZ was declared in 1978 (Jones 1990) caused a major reduction in the foreign catch. This reduction was offset by increasing domestic activity — catches by domestic vessels increased in the mid 1970s, and foreign charter activity increased rapidly after 1978 (Table 2).

Historically, the main JMA 7 jack mackerel fishery has operated from November until about March or April, in the North and South Taranaki Bights (Jones 1990, Horn 1991b), although it is obvious from data compiled during the present study that effort is reasonably constant throughout the year, with a more southerly component occurring between May and October (Figure 1) that is defined as winter for the analysis. This southerly component is probably associated with the hoki target fishery on the South Island west coast.

2.3 Literature Review

Robertson & Grimes (Unpublished results) produced vulnerability and biomass estimates of *T. declivis* and *T. novaezelandiae* for the North and South Taranaki Bights based on data collected by *Tomi Maru No. 55* during a joint New Zealand/Japanese research programme between December 1980 and February 1981. They concluded that catch rate increased with towing duration, and that the low mean towing speed (3.25 kn) resulted in stock size being grossly underestimated. The larger and more powerful *Shinkai Maru* repeated the survey in October–November 1981, using a mean towing speed of 3.8 kn. Robertson *et al.* (1989) computed biomass values with upper and lower bounds rounded to the nearest 100 t for *T. declivis* and *T. novaezelandiae* based on this survey.

Horn (1991a) estimated instantaneous mortality for *T. declivis* and *T. novaezelandiae* using age-length data sets. From trawl survey data from the F.V. *Cordella* survey in February–March 1990, jack mackerel biomass in west coast waters between 37°30' and 41°30' S was estimated. He concluded that the *Cordella* and *Shinkai Maru* surveys were difficult to compare and that biomass estimates based on their data were not usable in a stock reduction analysis, so a biomass projection method was used to calculate virgin and current biomass.

Horn (1991b) described the stratified random trawl survey of the North and South Taranaki Bights and the northern South Island shelf to depths of 25–300 m using *Cordella* in February–March 1990. Its objective was to update the previous biomass estimates to enable comparisons with the 1981 *Shinkai Maru* survey, and to extend the sampling area to within the 12 n. mile territorial sea where, it was believed, most of the jack mackerel stocks occur (Horn 1991a, 1991b). The Territorial Sea had not been sampled during the earlier surveys.

Jones (1990) summarised available information on the biology and fisheries of *Trachurus* species within the New Zealand zone and the central South Pacific, and Horn (1993) described the growth, age structure, and productivity of *T. declivis* and *T. novaezelandiae* off the central west coast of the North Island.

3. REVIEW OF THE FISHERY

3.1 The Commercial Fishery

The commercial fishery for jack mackerels in JMA 7 (Figure 2) is made up of two components: small domestic vessels recording their catch on Catch Effort Landing Return (CELR) forms, and large deepwater trawlers, mainly foreign chartered, who record their catch on Trawl, Catch, Effort and Processing Return (TCEPR) forms. Records for both were incomplete for 1997 at the time data extracts were made for this report.

In the CELR fishery jack mackerel are taken as target and bycatch (Table 3). On average, more than 75% of the CELR jack mackerel catch since 1992 has been targeted (Table 4), although the annual proportions have been highly variable with high proportions of jack mackerel catch taken as bycatch in some years.

Some jack mackerel is taken as bycatch in the TCEPR fishery (Table 5), but the proportion of targeted catch (*see* Table 4) is much higher (generally 90–99%) and more consistent (except in 1995) than in the CELR fishery.

3.1.1 Catches and landings

From 1971 to 1977, the total foreign catch in New Zealand ranged between 13 000 and 18 000 t (Table 2). Most of this was taken in JMA 7 by Japanese vessels. The dramatic drop in Japanese catch after 1978, to a mean of about 3000 t, coincided with increasing domestic activity. The total catch of jack mackerel in New Zealand waters steadily rose to a peak of about 48 000 t in 1992–93, but has since been reduced to about 34 600 t in 1996–97 (Table 6).

In JMA 7, the highest recorded catch was 25 880 t in 1991–92 (*see* Table 6). From 1983–84 to 1989–90, the JMA 7 catch was about 70–80% of the New Zealand total, but more recently this proportion has dropped until, in 1995–96 and 1996–97, it was about 35%. This is probably a result of increased catches in JMA 3 because of the increased availability of *T. s. murphyi*, and decreased effort in the JMA 7 TCEPR fishery since 1994–95 (Table 7).

3.1.2 Effort

The number of tows in the JMA 7 TCEPR and CELR fisheries, by year and month since 1988–89, are shown in Tables 7 and 8. There is little effort targeting jack mackerel in the CELR fishery, although it may reach about 25% of the tow total between February and May. In the TCEPR fishery, targeting of jack mackerel occurs throughout the year, with peaks in December–January and June–July. The latter is probably related to activity in the hoki fishery.

Recent changes in the JMA 7 catch have been attributed to changes in fishing practices by Independent Fisheries Ltd and Sealord Ltd. After a 46% increase in total landings to 25 880 t in 1991–92 (*see* Table 6), landings decreased to 18 913 t in 1994–95. Industry members suggested that the decrease was largely due to the temporary withdrawal of a major company from the fishery until a code of practice to eliminate dolphin bycatch in the fishery was defined. Marketing constraints, described by Annala *et al.* (1998) for JMA 3, are also relevant here. The marked decrease to 12 270 t in 1995–96 is attributed to changes in fishing strategies (e.g., no midwater trawling at night) under the new code of practice, and withdrawal of a major company from the fishery for much of the season.

3.1.3 Management

Jack mackerels have been included fully in the Quota Management System (QMS) only since 1 October 1996, with 20% allocated to Maori. Previously jack mackerels were considered part of the QMS, although ITQs were issued only in JMA 7. In JMA 1 and JMA 3, quota for the fishery was fully allocated as IQs by regulation except for the 20% allocated to Maori.

Recent landings of jack mackerel in JMA 7 are considered to be sustainable and at levels which will allow the stock to move towards a size that will support the MSY (Annala *et al.* 1998). The current TACC is approximately equal to the MSY for *T. declivis* and *T. novaezelandiae* combined and is considered sustainable and at a level that will allow the stock to move towards a size that will support the MSY.

3.2 Traditional Maori Fishing

The traditional Maori take of jack mackerel has not been quantified.

3.3 Recreational Fishery

Recreational fishing surveys in the Ministry of Fisheries South (in 1991–92) and Central (in 1992–93) regions have shown that the recreational catch of jack mackerel (the surveys do not distinguish jack mackerels at the species level) is too small to be used to estimate harvest levels (Annala *et al.* 1998). The harvest estimates for jack mackerel from the recreational survey in the Ministry of Fisheries North region in 1993–94, and the National Survey in 1996, based on data from Bradford (1998), are shown in Table 9.

4. RESEARCH

4.1 The data

4.1.1 Species proportions

Because landings of jack mackerel are recorded on MFish data collection forms under the aggregate "JMA", reliable estimates of species proportions are required for apportioning total landings to estimate CPUE for each species as stock indices for the stock reduction model, and for estimating annual catch histories of the individual species.

Data which can be used to estimate species proportions are available from the following sources.

- The scientific observer database has total sample weights and weights of the component species from samples taken between 1990 and 1997.
- Robertson *et al.* (1989) included weights of *T. declivis* and *T. novaezelandiae* for each tow from the 1981 (October–November) central west coast biomass survey by the *Shinkai Maru*.
- The Trawl database contains catch weights of the three jack mackerel species from *Cordella*'s trawl survey in JMA 7 during February and March 1990 (*see* Horn 1991b).

Species proportions from Scientific Observer Programme data

Data were extracted from the MFish observer database to provide estimates of species proportions for 1990 to 1997. The method used was as follows.

- Species composition data and total catch by tow extracted from the observer database.
- Species proportions were estimated by weight and number for each tow.
- Species tow proportions were scaled to the tow tonnage.
- Means of the species tow weights for each trip were estimated.
- These species trip estimates were scaled to the trip tonnage.
- The species estimates were summed for all landings and proportions of the species in the catch were estimated for a given time frame.

A summary of the estimation method for species proportions is shown in Appendix 1.

Choice of a time frame over which to aggregate tow and tow-sample weights for estimates of species proportions was based on the frequency of samples over time. The aim was to produce a contiguous time series of species proportions with minimum interpolation of missing values. Species proportions by month and quarter were examined (Tables 10 and 11). Because of the lower frequency of missing values in the series aggregated by quarter, species proportions for input into the CPUE model were based on this unit of time. Where interpolation was necessary, the mean of the single values preceding and following the missing value was substituted.

A series of coefficients of variation (*CV*) was estimated by quarter for the sample species proportions (p_i) using

$$CV = \frac{se(p_i)}{mean(p_i)}.$$

The *CV*s were multiplied by the finite population correction

$$c = \sqrt{1 - \frac{t}{T}}$$

where t is the total tonnage examined and T is the total tonnage caught in the fishery over the reference time frame. Total tonnage was taken as the sum of CELR and TCEPR catches from the MFish catch and effort database. The *CV*s for quarterly periods are given in Table 12a.

Monthly maps of observed tows are shown in Figure 1b: the distributions are similar to those shown in Table 1a for all tows, though the density is much less.

An examination of vessel details for the observed data provided definitive information for 98 out of the 121 vessels that have carried observers in the fishery. All of these were large vessels over 70 m in length. The remaining 23 vessels probably had some error in callsign recorded by the observer, and 4 of these were redefined using observer reports. Although information on the remaining 19 vessels was not available, it is reasonable to assume that they are also large vessels because their recorded callsigns are similar to those of large foreign vessels. This suggests that all observed vessels are from the TCEPR fleet and that there has been no sampling of catches of small vessels fishing inside the 12 n. mile limit. Vessels equal to or larger than 43 m are prohibited within 12 n. miles.

Species proportions from Robertson *et al.* (1989)

Estimates of the proportions of *T. declivis* and *T. novaezelandiae* in the 1981–82 year were calculated using their weights in the 126 tows during the biomass survey. The proportion of species i is defined as

$$P_i = \frac{\sum_{j=1}^{n} w_{ij}}{\sum_{j=1}^{n}\sum_{i=1}^{2} w_{ij}}$$

where, w_{ij} is the weight of species i in the jth tow, and n is the total number of tows. The species proportions estimated for 1981–82 using this method were 0.44 for *T. declivis* and 0.56 for *T. novaezelandiae.*

Species proportions from trawl survey COR9001

Proportions were estimated using a similar method to that described above by Robertson *et al.* (1989). The same values were obtained (0.44 for *T. declivis* and 0.56 for *T. novaezelandiae*) for data collected outside 12 n miles, but because the data from the two surveys are not comparable (*see* Horn 1991b) the estimates for COR9001 were not used in the analysis.

4.1.2 Catch, effort, and related data

Both CELR and TCEPR data were considered for use in estimating stock indices and preliminary extracts were made to determine the nature of the datasets. The final extracts were based on these examinations. Because a relatively low proportion of CELR tows target jack mackerel (*see* Table 4), only the TCEPR data were included in the final extract. This decision was supported by results from examination of the observed vessels (Section 4.1.1) which showed that all observed vessels were from the TCEPR fleet. Therefore, no estimates of species proportions in the catch from the CELR fleet are available.

To simplify estimates of effort, only tows targeting jack mackerel were used. To allow an examination of spatial distribution (*see* Figure 1), estimated weights were extracted because tow-start positions as latitudes and longitudes are available only from this dataset.

A number of data fields were extracted for each tow from the MFish catch and effort database to provide standardised stock indices based on CPUE for 1990 to 1997. These were vessel code, date and time of tow start, date and time of tow finish, length of the tow in minutes, fishing year, gear type, target species, statistical area, tow start latitude and longitude, wingspread, headline height, towing speed, bottom depth, ground-rope depth, total catch (all species), and jack mackerel catch.

CPUE (U) was estimated for each tow using

$$U = C/d$$

where C is the weight of jack mackerel in the tow and d is the distance of the tow. Towing distance was estimated as

$$d = s * t$$

where s is the mean towing speed for the tow, and t is the duration of the tow in hours. Towing speed is recorded once at the beginning of the tow and may be a poor estimator of mean vessel speed.

Vessel specifications data were supplied by MFish. These were vessel code, nation, the year the vessel was built, the number of crew members, length overall, breadth, gross tonnage, draught, power in kilowatts, whether the vessel had processing capabilities, whether the vessel had a meal plant, and the freezing capabilities of the vessel.

4.1.3 Exploratory data analysis

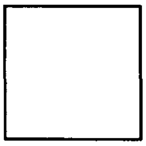
The CPUE data were examined for outliers initially by looking at the distribution of each variable using scatterplots and stem and leaf displays. The distributions were then checked against known ranges suggested by members of the fishing industry with experience in the fishery. There was some uncertainty about what was reasonable, however, because many vessels that had been active in the fishery were foreign flagged, and some details were not well known. Generally, gross outliers were determined from the distribution plots and industry information allowed better choice of some gear-related variables.

Examination of vessel speed, headline-height, and wingspread resulted in erroneous records being identified. Where vessel speed was outside the range 3.5–6.5 kn, headline-height was greater than 130 m, or wingspread greater than 330 m, the record was discarded.

Initially, some confusion arose when considering the difference between midwater and bottom trawls. Analysis showed that in 5581 tows out of a total 10 321 where midwater trawl gear was used (about 50%), ground-rope depth was equal to bottom depth. A simple interpretation suggests that midwater gear is often used at the bottom, and this may be true, but alternative suggestions are that the gear was flown above the bottom for some unknown portion of the tow, or that one of the fields was filled out incorrectly.

Further analysis focused on the relationship between wingspread and headline height, based on the understanding that the relative cross-sectional shapes of bottom and midwater trawl gear are represented by (a) and (b) below respectively (Neil Bagley, NIWA, pers. comm.), although this figure is not intended to represent relative size.

(a) Cross-sectional shape of bottom trawl gear



(b) Cross-sectional shape of midwater trawl gear

Scatter plots of headline height on wingspread showed that generally an approximation of this relationship held: in most tows where gear-type was recorded as bottom trawl, headline height was less than 10 m and the mean wingspread was about 37 m (Figure 3). This was largely true for data recorded by vessels of all nations.

The situation for tows where gear-type was recorded as midwater trawl differed by nation. For New Zealand and Japanese flagged vessels, the headline height to wingspread ratio was often about equal to unity, clustering fairly tightly around 40–50 m for each variable. By contrast, the Russian and Ukranian data indicated a shape closer to (a) above, with mean headline height being considerably less than wingspread, although the scale was about an order of magnitude greater than for the bottom trawl data. One interpretation is that Russian vessels have deployed their midwater gear on the bottom more frequently than the other nations.

A number of bottom trawl data points (603 points) lay outside the headline height:wingspread range of most of the data (10 763 points) — they can be seen as the points over 20 m headline height, clustering about the unity line on the "All Data" plot in Figure 3. Determining the reason for this was difficult. Examination of the data prompted the conclusion that the data were spurious, although this was inconclusive for the few points recorded by Russian vessels.

There are two possible reasons for the values being out of range: the points may have been midwater shots incorrectly coded as bottom trawl, or they may have been bottom trawl shots that had gained an order of magnitude as a data-entry error (e.g., omission of a decimal point). Because of the confusion surrounding these data points, and considering that they represent less than 4% of the total dataset, they were discarded.

4.1.4 Biological parameters

Except for "steepness" of the stock-recruitment relationship, biological parameters used in the stock reduction model were taken from Horn (1991a) and are presented in Table 13. Horn (1991a, 1993) recorded no difference between males and females for growth and the length-weight relationship.

"Steepness" for the Beverton and Holt stock-recruitment relationship was determined as the mean "steepness" from data presented for the Order Perciformes, which includes *Trachurus* species, by Myers *et al.* (1995). "Steepness" values (h) were calculated for each listed species using

$$h = \frac{0.2}{1 - \left(\frac{0.8R_0}{\alpha K} \right)}$$

where R_0 is the geometric mean of all the observed recruitment in the series as calculated by Myers *et al.* (1995) and α and K are parameters from the spawner-recruitment relationship as used by Myers *et al.* (1995).

Sixteen values of h were estimated using information from 11 species, but the wide range of these values (from 0.2 to 1.0; *see* Table 14) was unsatisfactory. Because a number of these species are dissimilar both morphologically and physiologically from *Trachurus* species, they were excluded from the estimation. Therefore, in estimating a reasonable value of h for *T. declivis* and *T. novaezelandiae*, calculation of the mean was restricted to the estimated values of h for members of the family Carangidae (*T. capensis* and *T. trachurus*) and "mackerels" of the family Scombridae (*Scomber japonicus* and *S. scombrus*), although one value for *S. scombrus* (h = 0.35) lay well outside the range of values and was discarded. The resulting estimate of h was 0.924.

4.1.5 Catch history

A catch history (*see* Table 1) spanning 51 years (1946 to 1996–97) was generated using data from Marine Department Reports on Fisheries (1944–74), FSU data for 1975–83 from King (1985, 1986) and King *et al.* (1986), and FSU, CELR, and LFRR data for 1983–84 to 1996–97 from Annala *et al.* (1998). These data were converted to tonnes where necessary (early records are in hundredweight), and values assigned to the three *Trachurus* species using the estimates of species proportions in Table 15.

Estimates of species proportions did not cover the entire period of the catch history. Before 1985–86, only those for 1981–82 were available, based on data from Robertson *et al.* (1989). They were applied to the catch from 1946 to 1981–82. Because of differences in gear parameters between the 1981–82 and 1989–90 surveys (Horn 1991b), and because *Shinkai Maru* is more comparable with observed TCEPR vessels than *Cordella*, the estimates from the 1989–90 trawl survey data were discarded. For the remaining years without data (between 1981–82 and 1985–86), means of the 1981–82 and 1985–86 estimates were used for each species.

Observer samples provided data for estimates over the period 1985–86 to 1996–97 which were calculated using the same method as for the quarterly estimates in the CPUE analysis (Appendix 1), but here the estimates were to be used for producing annual catch histories for each species and were therefore based on data aggregated over fishing year. A series of *CV*s for the annual mean sample proportions, calculated as for quarterly species proportions, is shown in Table 12b.

4.2 Stock indices from CPUE

Abundance indices for JMA 7 were generated using CPUE data from 1990 to 1997 when data from observer sampling allowed estimation of species proportions. The estimated species proportions were used to multiply total jack mackerel catch to determine catch weights of each of the *Trachurus* species. Four time series of CPUE were examined to determine the influence of using subsets of the data.

1. All species – *T. declivis*, *T. novaezelandiae*, and *T. s. murphyi* ($CPUE_1$).
2. *T. declivis* and *T. novaezelandiae* ($CPUE_2$).
3. *T. declivis* ($CPUE_3$).
4. *T. novaezelandiae* ($CPUE_4$).

Initial examination of the distribution of tow positions in time and space (*see* Figure 1) in conjunction with a time series plot of $CPUE_1$ (Figure 4), suggested the possibility of two separate fisheries: one operating during November to April in a more northerly (North and South Taranaki Bight to Cook Strait) area with a peak CPUE during January–February, and the other operating from May to October from North Taranaki Bight to the central west coast (South Island), probably in conjunction with the hoki fishery, with a CPUE peak usually in June or July. To accommodate any differences between these “fisheries”, the four CPUE series were further divided to provide “summer” (November to April) and “winter” (May to October) series. The time series of species proportions by quarter (Table 11) suggests different species compositions in the two fisheries, with a higher proportion of *T. s. murphyi* in the winter (quarters 2 and 3).

4.3 Standardisation of the stock indices

The MFish data on which these CPUE estimates are based were recorded on many different vessels fishing under different conditions at different positions and times of the year. Consequently, CPUE from different tows cannot be compared directly. To quantify as much variability arising from these differences as possible, and to standardise the relative estimates of annual CPUE being produced as stock indices, a linear model was fitted to each of the CPUE datasets, similar to that described by Vignaux (1994).

The CPUE linear model was constructed in the New S programming environment using the functions "lm", "step", and "glm". Under the assumption that CPUE is proportional to the product of the explanatory terms and error, a model of the form

$$\log(CPUE) = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \ldots + \alpha_n x_n + \varepsilon$$

was assumed, where α_0 is the coefficient from the intercept of the regression, α_1 to α_n are the coefficients from the explanatory variables x_1 to x_n, and ε is the error term or residual. In this form, linear regression can be applied to the data.

The error term, ε, was assumed to be normal with mean of 0 and constant variance. To allow the inclusion of tows with zero CPUE, a constant term equal to 1% of the minimum non-zero value in a particular CPUE series was added to each value in that series as follows

Series	"Winter" fishery	"Summer" fishery	Combined fisheries
$CPUE_1$	5.75×10^{-8}	4.13×10^{-6}	5.72×10^{-7}
$CPUE_2$	3.75×10^{-8}	3.43×10^{-6}	3.75×10^{-8}
$CPUE_3$	3.75×10^{-8}	5.00×10^{-7}	3.75×10^{-8}
$CPUE_4$	5.58×10^{-7}	1.84×10^{-6}	5.58×10^{-7}

Applying the model required six steps:

1. fitting the linear model of log(CPUE + constant) to the categorical variable "year" (using the S function "lm");
2. following a stepwise strategy to select additional explanatory variables (using the S function "step");
3. the model resulting from Step 2 was refitted (using the S function "lm") and F statistics from an analysis of variance (ANOVA) were examined to determine which of the fitted explanatory variables should be included in the final model — *p* values (probability of *F*) of 10^{-5} or less were considered significant;
4. after a model was constructed from significant variables the final model was refitted (using the S function "lm") by manually adding the significant variables in the order that they were fitted previously, to determine the cumulative R^2 with each fitted variable. If the R^2, rounded to two significant decimal places, did not increase with the addition of three variables, the two most recent additions were discarded from the model — this ensured

that any additional increase in the R^2 value was not overlooked;

5. residuals for each of the fitted explanatory variables were plotted and examined; normality of the residuals was examined using quantiles of the standard normal distribution;
6. a time series of year effects were generated according to the method described by Vignaux (1994).

Including "year", 22 possible explanatory variables were passed to the "step" function at Step 2 above (Table 16). Except for "moonphase", many had come from either the MFish catch/effort database (latitude, longitude, bottom depth, vessel speed, gear, wingspread, headline height, finish time) or the MFish vessel information database (nation, year built, crew number, power, length, breadth, draught, tonnage). "Year" and "month" were extracted from the date the tow was started; "bycatch" was estimated by subtracting the jack mackerel catch from the total catch; "year built" was re-expressed as "age" by subtracting it from 1998; "length*breadth*draught" (*see* Vignaux 1996) was estimated from the constituent data; and "relative depth" was estimated by subtracting "ground rope depth" (from the MFish catch/effort database) from "bottom depth".

Year, month, vessel nationality, and gear-type were included in the model as categorical variables, the rest as continuous variables.

The meaning of most of the variables is clear from their names but some additional explanation is necessary. Often recording of the variable on board the vessel (date, latitude, longitude, bottom depth, vessel speed, gear, wingspread, headline height) occurs at the beginning of the tow. "Gear" is a record of the type of net used — midwater or bottom trawl are the two possibilities; "finish time" is the time of day that the tow was hauled; "nation" refers to the country flag of the vessel; "crew number" is the number of crew on board. Vessel measurements (length, breadth, draught) are in metres.

The assumption that the residuals are distributed normally was tested using plots of the residuals against quantiles of standard normal (Figure 5) and scatter plots of the residuals from each of the explanatory variables. Some typical examples of the latter are shown in Appendix 3. These plots suggested some skewness, but no indication of serious violations of the model assumptions (*see*, for example, Venables & Ripley (1994)).

The fit of "year" was always significant (Table 17). In the CPUE series 2–4, "month" was always the second variable to enter the model, with nationality being the most commonly selected as the next two variables, and vessel-volume and various orders of polynomial for longitude being most common after that.

The situation was different in the series CPUE_1. No clear pattern was evident in the second position, although month occurred either in the third (winter and combined series) or the fourth position (summer series). This difference in response between CPUE_1 and the other CPUE series, which had been modified with the application of factors of species proportions, may indicate some systematic bias in the latter. The R^2 for the derived series (2–4) is generally higher than for CPUE_1. While it was not possible to investigate this further in the present study, estimation of confidence bounds around the species proportions factors may be obtained by bootstrapping the estimated tow sample proportions and trip proportions. This issue could be taken up in future work.

Some high values of R^2 were obtained, suggesting up to 74% of variation in the CPUE is accounted for by the fitted variables (*see* Table 17). However, these results are difficult to interpret considering that the species proportions estimates are based on a low sampling rate of total tows within the fleet.

The estimated year effects are summarised in Table 18. Year effects for the summer and winter fisheries in the series $CPUE_3$ (*T. declivis*) and $CPUE_4$ (*T. novaezelandiae*) were used as stock indices in the age structured model. This provided four stock indices, two for each species.

4.4 The age-structured model

A deterministic stock reduction model, similar to that of Francis (1990), was used for testing the feasibility of using age-structured models to produce estimates of virgin biomass of *T. declivis* and *T. novaezelandiae* in JMA 7 (Appendix 2). The model was constructed as a spreadsheet in Microsoft Excel 97, and was computed by minimising the sum of squares of the difference between observed stock index and the stock index predicted by the model. The Excel "solver" function was used for the minimisation, with iterations based on changes to the input values of virgin recruitment (R_0) for each species.

The model required growth and length-weight parameters, an estimate of natural mortality, age at recruitment, maximum age, von Bertalanffy growth parameters, a value for steepness of the Beverton and Holt stock-recruitment relationship, ages at maturity and recruitment, a complete catch history of each species from the fishery, and at least one index of stock abundance.

The four stock indices referred to above were included in the model as observed indices. Separate predicted indices were estimated for each, and the sum of squares (*SS*) for the difference between each of the observed and predicted series was calculated. A total sum of squares for all was used as the function value below.

A number of starting values for R_0 were passed to the solver function (Table 19). The model then produced a time series estimate of biomass based on the minimised sum of squares. The estimated biomass series and the fit between the observed and predicted stock indices were plotted (Figure 6). Values of virgin biomass (B_0) and R_0 for each species, and the minimised sum of squares, were recorded for each model run. The model run with the lowest value of *SS* was taken as providing the best estimates of R_0 and B_0. The estimates are shown in Table 19.

Residuals from observed and predicted stock indices were plotted and are shown in Figure 7. Several outliers are evident in the plots: in particular, the values 5.68 and 6.30 in the summer and winter fisheries for *T. novaezelandiae* in 1990, and the values 3.62 and 5.68 in the summer fishery for *T. declivis* in 1992 and 1997, were of concern. The model was re-run using a robust likelihood estimator (*RL*) to minimise their effect, thus testing their influence on the earlier runs where the *SS* was minimised. The estimator, formulated by Fournier *et al.*(1990), is

$$-\ln(\exp(-1*(\ln(I_{obs})-\ln(I_{pred}))^2/(2*(\sigma)))+0.01)$$

where I_{obs} and I_{pred} are the observed and predicted stock indices, and σ is the assumed standard deviation of the error term. Observed and predicted stock indices from the *RL* approach are shown in Figure 8, and residuals from the observed and predicted stock indices are shown in Figure 9.

Best estimates of R_0 and B_0 are shown in Table 19. The estimate of B_0 for *T.declivis* from the *RL* approach shows an increase by a factor greater than 3.5 from that computed using the minimised *SS* approach, suggesting that the outliers referred to above exert a large amount of influence on the model for this species. There is no change in R_0 and B_0 for *T. novaezelandiae* using the two methods.

Some sensitivity to starting values was observed in the model runs. When minimising the *SS* (*see* Table 19), similar values of R_0 and B_0 were evident for both species with starting values of 17 and 18, but other starting values produced quite different results. The model minimising *RL* was only a little more stable in that it produced similar results for both species with the three starting values, 17, 18, and 20.

To complete the study, estimates of R_0 and B_0 from both the *SS* and the *RL* approaches were used as inputs to the yield per recruit analysis and for estimation of *MCY* respectively.

4.5 Yield per recruit analysis

The yield per recruit analysis was constructed in Excel 97 according to the equations presented in Appendix 2. A series of yield estimates (*CAY*) was produced for each species by passing a series of values for fishing mortality (*F*) to the routine. Yield per recruit curves for each species were produced by plotting these yield values with the values for *F* (Figure 10).

Values for $F_{0.1}$ were estimated from the yield per recruit relationship, based on the definition that $F_{0.1}$ is where the rate of change of yield with respect to *F* is 0.1 times that at the origin. Slope at the origin was estimated as the slope between the estimated yield values for $F = 0$ and $F = 0.001$, an arbitrary small number. An iterative method was then used to find the value of *F* corresponding to the point on the curve where its slope was 0.1 times the value estimated for the origin. The iterative process used values estimated for yield from various values of *F* and $F + 0.001$ along the yield per recruit curve.

The estimated $F_{0.1}$ values are 0.7149 for *T. declivis*, and 0.8999 for *T. novaezelandiae*, which are high compared with those estimated for JMA 7 by Horn (1991a) and summarised by Annala *et al.* (1998). However, these values appear reasonable in terms of the biological parameters used in the model and the high rate of growth associated with them. Based on examination of virgin cohort weight (Table 20), both species show peak biomass levels early in their life histories, at age 6 for *T. declivis* and age 5 for *T. novaezelandiae*.

5. STOCK ASSESSMENT

5.1 Biomass Estimates

Estimated B_0 values from the stock reduction model are 67 933 t and 246 305 t for *T. declivis*, and 57 463 t for *T. novaezelandiae*. The values for *T. declivis* are from the minimisation of the *SS* and *RL* respectively; there was no change between methods for *T. novaezelandiae*.

5.2 Estimation of Maximum Constant Yield (*MCY*)

MCY was estimated using method 1 of Annala *et al.* (1998)

$$M\hat{C}Y = 0.25F_{0.1}B_0.$$

The values are 12 141 and 42 938 t for *T. declivis*, based on the B_0 values from the minimisation of the *SS* and *RL* respectively, and 12 928 t for *T. novaezelandiae*.

5.3 Estimation of Current Annual Yield (*CAY*)

CAY was estimated using the method of Annala *et al.* (1998)

$$CAY = E_{0.1}B_{current}.$$

The values are 6358 and 23 052 t for *T. declivis*, based on the minimisation of the *SS* and *RL* respectively, and 7758 t for *T. novaezelandiae*.

6. DISCUSSION

The stock reduction model is used in this study as an example of an age-structured stock assessment model, and the feasibility of using this family of models is investigated by working through the steps for producing estimates of B_0 and $F_{0.1}$ using this specific model, and, subsequently, estimates of CAY and MCY. The stock reduction model, as it is used here, is simplistic in that it uses deterministic recruitment. Age frequency information from the year-to-year catch would provide information on year class strength which could be included, thereby improving the model estimates. The biggest problem in taking this step is that although otoliths are available from Scientific Observer Programme activity in JMA 7 over several years, *T. s. murphyi* cannot be aged at this time, thus preventing the inclusion of age class strength for this species.

However, a more critical point underlying the methodology is the reliability of the species proportions estimates. An indication of the variability between species tow-proportions estimates is given by the *CV*s in Table 12. A reasonable *CV* in this context would be about 0.05 (Dave Gilbert, NIWA, pers. comm.), but a high proportion of the estimated *CV*s are considerably higher. Generally, lower *CV*s correspond to higher rates of sampling, although there is some difference between *T. declivis* and the other species, possibly because the former are more frequently represented in the samples.

An alternative method of estimating the *CV*s would be to base them on a bootstrap of the observer samples. This would provide a check for any bias in the means and a method of estimating confidence intervals that is not reliant on the assumption of normality. However, such an approach could not improve values of the *CV*s to within the acceptable target range of 5–10%.

One criticism of the methodology is that CPUE series estimated with such imprecise factors as the quarterly species proportions will not benefit from standardisation using linear modelling. While this may be true, it can be seen from Table 17 that the fits of the modified CPUE series are similar to those of the unmodified series (CPUE_1), which are statistically significant with a relatively large amount of the variability explained by the fitted terms (17–29%). Fits to the modified series are also significant, with high R^2 values.

These results suggest that the methodology produces reasonably standardised stock indices. However, there are two notable features that require further analysis. Firstly, in the modified series "month" is consistently fitted in the second position, where it had been fitted in the third or fourth position for the unmodified CPUE series. Secondly, the amount of variability explained by the fitted terms is consistently higher for the modified series. Since the use of species proportions is effectively a weighting of the original CPUE data, these results may indicate that some quarters are being substantially, and wrongly, down-weighted through sampling variability, and/or that the species proportions are biased, but a more informed conclusion requires further work. Re-running the methodology, based on bootstrapped sample weights (*see* Section 4.3), may provide more information on the variability in the year effects.

The ideal would be to have proportions from each tow which could then be used to directly modify the values of CPUE for each tow, rather than to apply some mean value over an extended time frame like month or quarter. However, the observer coverage required to do this would probably be too high to be acceptable. Simulation techniques may be able to establish the amount of coverage required for the *CV*s of tow proportions to be reduced to an acceptable level.

Whatever the outcome, stock indices based on species proportions and catch data from only the TCEPR fishery cannot be indicative of the JMA 7 jack mackerel population if the spatial distribution of the three species is considered. Horn (1991a) referred to a large proportion of the *T. novaezelandiae* resource being unavailable to TECPR vessels because it occurs in shallower waters or within the 12 n. mile that cannot be fished by vessels over 43 m in length. The absence of observer data from the CELR fishery makes this a difficult problem to address.

The performance of the stock reduction model, based on these data, is unacceptable. The major difference in the B_0 values for *T. declivis* estimated from the two minimisation methods (*SS* and *RL*) is a serious cause for concern. The more than threefold increase suggests a huge influence of the outliers, and examination of Figures 6 and 8 shows that the fit of the predicted stock indices is extremely poor. Reasons for the extreme CPUE values are unknown, but there are several possibilities that could be examined further: the level of misidentification of *T. s.*

murphyi could vary with different observers; variations in targeting by size/species could occur; and the seasonal/areal distributions could vary in a more complex manner than the simple summer/winter pattern that has been assumed here. Whatever the underlying cause, the problem is most likely related with uncertainty in the estimates of species proportions, and the method of assigning the proportions to the raw CPUE by quarter.

In summary, the feasibility of developing age-structured stock assessment models for *T. declivis* and *T. novaezelandiae* depends on estimating species proportions that have lower, more acceptable levels of variance than was possible here. This point is critical and must be met before any level of reliability is possible in producing a stock assessment for these species in JMA 7. It may be possible to address this problem in the future by increasing the level of observer sampling, if calculated levels proved to be possible. The need to expand sampling to include the CELR fishery, based on Horn's (1991a) information that the inshore area is represented by a high proportion of *T. novaezelandiae*, would ensure that future estimates of species proportions are based on data including adequate coverage of the spatial range of the two species in JMA 7.

Because of the high level of uncertainty in the species proportions estimates used in this study, none of the outputs from the stock reduction model and yield per recruit analysis presented here can be used in management of the JMA 7 Fishstock.

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Table 1: Catch history of jack mackerel species in JMA 7, 1946–1997, best estimates of annual landings (t). "All species" is *Trachurus declivis*, *T. novaezelandiae*, & *T. symmetricus murphyi*, JMD is *T. declivis*, JMM is *T. symmetricus murphyi*, and JMN is *T. novaezelandiae* (Sources: 1946–74, Marine Department Reports on Fisheries; 1975–83, FSU data; 1983–96, FSU, CELR, and LFRR data)

Year	All species	JMD & JMN	JMD	JMN	JMM
1946	6	6	2.64	3.36	0
1947	2	2	0.88	1.12	0
1948	4	4	1.76	2.24	0
1949	19	19	8.36	10.64	0
1950	0	0	0	0	0
1951	0	0	0	0	0
1952	7	7	3.08	3.92	0
1953	9	9	3.96	5.04	0
1954	1	1	0.44	0.56	0
1955	11	11	4.84	6.16	0
1956	2	2	0.88	1.12	0
1957	6	6	2.64	3.36	0
1958	9	9	3.96	5.04	0
1959	0	0	0	0	0
1960	4	4	1.76	2.24	0
1961	4	4	1.76	2.24	0
1962	5	5	2.2	2.8	0
1963	12	12	5.28	6.72	0
1964	10	10	4.4	5.6	0
1965	7	7	3.08	3.92	0
1966	53	53	23.32	29.68	0
1967	7 559	7 559	3 325.96	4 233.04	0
1968	7 559	7 559	3 325.96	4 233.04	0
1969	7 559	7 559	3 325.96	4 233.04	0
1970	6 333	6 333	2 786.52	3 546.48	0
1971	10 532	10 532	4 634.08	5 897.92	0
1972	14 556	14 556	6 404.64	8 151.36	0
1973	12 009	12 009	5 283.96	6 725.04	0
1974	14 598	14 598	6 423.12	8 174.88	0
1975	10 434	10 434	4 590.96	5 843.04	0
1976	12 540	12 540	5 517.60	7 022.40	0
1977	13 979	13 979	6 150.76	7 828.24	0
1978	4 993	4 993	2 196.92	2 796.08	0
1979	5 737	5 737	2 524.28	3 212.72	0
1980	3 458	3 458	1 521.52	1 936.48	0
1981	8 061	8 061	3 546.84	4 514.16	0
1982	7 664	7 664	3 372.16	4 291.84	0
1983	9 892	9 892	5 539.52	4 352.48	0
1983–84	12 464	12 464	6 979.84	5 484.16	0
1984–85	16 013	16 013	8 967.28	7 045.72	0
1985–86	10 002	10 002	6 801.36	3 200.64	0
1986–87	19 815	19 815	11 492.70	8 322.30	0
1987–88	17 827	17 827	10 339.66	7 487.34	0
1988–89	17 402	16 183.86	10 963.26	5 220.60	1 218.14
1989–90	21 776	21 558.24	6 315.04	15 243.20	217.76
1990–91	17 786	17 252.42	6 758.68	10 671.60	355.72
1991–92	25 880	23 550.80	11 904.80	11 646.00	2 329.20

Table 1 — *Continued*

Year	All species	JMD & JMN	JMD	JMN	JMM
1992–93	24 767	20 556.61	14 612.53	6 191.75	3 962.72
1993–94	22 377	13 873.74	7 831.95	6 041.79	8 503.26
1994–95	18 913	12 482.58	5 673.90	6 808.68	6 430.42
1995–96	12 270	7 239.30	4 417.20	2 822.10	5 030.70
1996–97	12 056	10 247.60	6 992.48	3 255.12	1 808.40

Table 2: Total landings (t) in New Zealand EEZ by nation 1970 to 1987–88. (Source: Annala *et al.* 1998)

	Domestic	Chartered	Foreign licensed vessels				Grand
Year	**vessels**	**vessels**	**Japan**	**Korea**	**Russia**	**Total**	**total**
1970	250	–	8 128	–	–	8 128	8 378
1971	631	–	13 301	–	–	13 301	13 932
1972	586	–	18 070	–	600	18 670	19 256
1973	723	–	14 964	–	200	15 164	15 887
1974	1 473	–	17 738	–	100	17 838	19 311
1975	317	–	13 486	–	–	13 486	13 803
1976	1 044	–	15 145	–	400	15 545	16 589
1977	1 719	–	14 539	1534	700	16 773	18 492
1978	1 817	2[#]	4 786	–	–	4 786[#]	6 605
1979	3 131	631[#]	3 187*	–	640	3 827[#]	7 589
1980	3 320	N/A	1 254*	–	–	1 254	4 574
1981	3 542	3 136	3 983*	–	–	3 983	10 664
1982	2 822	4 380	2 936*	–	–	2 936	10 138
1983	2 604	5 997	4 140	345	0	4 485	13 086
1983–84[†]	4 458	8 035	3 599	764	0	4 363	16 856
1984–85	3 363	9 786	5 332	1 091	0	6 423	19 572
1985–86	4 117	8 015	1 573	1 083	0	2 656	14 788
1986–87	7 190	16 022	2 950	595	0	3 545	26 757
1987–88	6 854	13 045	2 106	624	0	2 730	22 629

[*] Japanese fisheries data (annual)

[#] 1 April– 31 March year.

[†] 1 October – 30 September year from 1983/84.

(Source = FSU. The slight difference in total catch given in Table 1 and this table for 1983–84 to 1985–86 arises from the different methods used to summarise data. The 1986–87 and 1987–88 FSU data are derived independently from that of the QMS.)

Table 3: Estimated catch (t) of jack mackerel by year and target species recorded on CELR forms in JMA 7

Fishing year	Target species					
	BAR	EMA	HOK	JMA	KAH	Total
1988–89	0.5			0.1	108.0	108.6
1989–90	10.1	648.0	5.0	1133.3	1723.0	3519.5
1990–91	40.4	820.0	2.0	2491.9	1309.2	4663.5
1991–92	23.1	25.0	0.0	3451.2	713.5	4212.8
1992–93	59.3	453.0	1.0	6929.4	550.0	7992.8
1993–94	5.8		0.3	4326.1	265.9	4598.1
1994–95	33.3	25.0	2.2	2580.2	180.0	2820.7
1995–96	41.3	70.0	0.4	1177.1	207.4	1496.3
1996–97	81.5	40	1.1	143.5	49.0	315.0
Total	295.3	135	12	22232.8	5106	29727.3

BAR	barracouta	*Thyrsites atun*
EMA	blue mackerel	*Scomber australasicus*
HOK	hoki	*Macruronus novaezelandiae*
JMA	jack mackerel	*Trachurus* sp.
KAH	kahawai	*Arripis trutta*

Table 4: Proportions of catch taken by target and bycatch in the CELR and TCEPR fisheries in JMA 7

	CELR		TECPR	
Year	Target	Bycatch	Target	Bycatch
1989	—	—	0.89	0.11
1990	0.32	0.68	0.94	0.06
1991	0.53	0.47	0.96	0.04
1992	0.82	0.18	0.98	0.02
1993	0.87	0.13	0.99	0.01
1994	0.94	0.06	0.96	0.04
1995	0.91	0.09	0.82	0.18
1996	0.79	0.21	0.95	0.05
1997	0.46	0.54	*—	*—
All years	0.75	0.25	0.95	0.05

*TECPR data were incomplete at the time of data extract

Table 5: Estimated catch (t) of jack mackerel by year and target species recorded on TECPR forms in JMA 7; species codes as in Table 3

Fishing year	Target species			
	BAR	HOK	JMA	Total
1988–89	416.5	180.3	4478.7	5075.5
1989–90	658.2	347.1	11945.1	12950.4
1990–91	294.3	882.1	10534.8	11711.2
1991–92	175.6	1124.3	21744.9	23044.8
1992–93	267.5	431.0	19126.1	19824.6
1993–94	625.6	1996.9	15637.8	18260.3
1994–95	973.6	1896.1	12733.8	15603.5
1995–96	471.1	2023.9	7607.0	10102.0
1996–97	611.3	1177.2	8811.0	10599.5
Total	4493.7	10058.9	112619.2	127171.8

Table 6: Recent catches of jack mackerel in JMA 7 and all New Zealand waters; proportion of JMA 7 catch relative to the New Zealand total. (Source: Annala *et al.* 1998)

Fishing year	Total NZ catch	JMA7 catch	Proportion
1983–84	16 880	12 464	0.74
1984–85	19 659	16 013	0.81
1985–86	14 773	10 002	0.68
1986–87	25 509	19 815	0.78
1987–88	22 818	17 827	0.78
1988–89	22 308	17 402	0.78
1989–90	30 102	21 776	0.72
1990–91	30 661	17 786	0.58
1991–92	38 676	25 880	0.67
1992–93	47 778	24 767	0.52
1993–94	45 748	22 377	0.49
1994–95	38 264	18 913	0.49
1995–96	38 947	12 270	0.32
1996–97	34 655	12 056	0.35

Table 7a: Number of tows in JMA 7 TCEPR (jack mackerel target) fishery; by fishing year and month. (Source: MFish catch and effort database)

	Fishing year										
Month	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	†Mean
Oct	–	227	50	271	247	341	145	25	48	78	159
Nov	–	141	2	284	281	184	71	1	82	137	131
Dec	–	133	77	450	395	366	278	32	87	150	219
Jan	–	92	221	306	365	422	418	221	80	136	251
Feb	–	176	104	71	190	122	–	61	57	74	107
Mar	–	255	140	123	220	–	82	75	16	78	124
Apr	–	226	56	150	232	–	–	65	13	278	146
May	145	128	72	488	202	215	168	120	173	–	190
Jun	70	213	426	402	257	410	403	265	233	–	298
Jul	26	165	78	201	145	278	297	413	234	–	204
Aug	120	201	61	13	4		54	62	85	–	75
Sep	348	152	229	148	122	212	32	36	268	–	172
Total	709	2109	1516	2907	2660	2550	1948	1376	1376	984	

† Means calculated using cells with a value > 0

Table 7b: Number of tows in JMA 7 TCEPR fishery, all targets*; by fishing year and month. (Source: MFish catch and effort database)

	Fishing year										
Month	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	†Mean
Oct	–	228	64	275	252	395	179	87	183	110	197
Nov	–	143	11	314	283	186	84	32	106	148	145
Dec	–	146	80	481	398	372	306	50	125	167	236
Jan	–	102	224	341	368	423	516	273	105	150	278
Feb	–	184	106	72	203	124	50	108	116	90	117
Mar	–	266	145	124	220	1	113	132	82	96	131
Apr	–	232	56	153	238	2	29	170	126	324	148
May	149	128	72	490	202	232	224	220	262	–	220
Jun	73	221	444	450	291	442	535	396	376	–	359
Jul	110	263	211	426	230	606	671	791	433	–	416
Aug	388	635	661	166	56	255	382	228	327	–	344
Sep	509	389	344	184	217	548	291	283	481	–	361
Total	1229	2937	2418	3476	2958	3586	3380	2770	2722	1263	

* Barracouta, blue mackerel, hoki, & jack mackerel

† Means calculated using cells with a value > 0

Table 8a: Number of tows in JMA 7 CELR (jack mackerel target) fishery by fishing year and month. (Source: MFish catch and effort database)

	Fishing year								
Month	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1997–98	†Mean
Oct			5	1	5				4
Nov	4	2	2		17		4	1	5
Dec	1	5	4	3	12		5	2	5
Jan	1	4	10	13	6		3		6
Feb	4	3	2	22	15	17	6		10
Mar	5	5	15	19	17	12	8	1	10
Apr	2	13	7	14	29	22	11	3	13
May	1	20	4	13	15	27	7	3	11
Jun		1	1	9	7	15	3		6
Aug			1						1
Sep				1					1
Total	18	53	51	95	123	93	47	10	

† Means calculated using cells with a value > 0

Table 8b: Number of tows in JMA 7 CELR fishery (all targets*) by fishing year and month. (Source: MFish catch and effort database)

	Fishing year								
Month	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1997–98	†Mean
Oct	5	88	53	84	28	5	40	58	45
Nov	63	122	45	45	48	18	36	125	63
Dec	18	67	90	63	20	15	28	48	44
Jan	16	52	46	46	9	20	21	92	38
Feb	49	100	32	81	15	60	19	20	47
Mar	44	70	55	104	24	41	34	45	52
Apr	40	82	33	77	55	64	46	84	60
May	90	68	60	106	35	97	96	25	72
Jun	30	5	36	79	42	40	74	69	47
Jul	4	19	49	16	2	33	32	11	21
Aug	7	18	14	56	7	18	18		20
Sep	51	42	14	60	11	18	21		31
Total	417	733	527	817	296	429	465	577	

* Barracouta, blue mackerel, hoki, kahawai, & jack mackerel

† Means calculated using cells with a value > 0

Table 9: Estimated number of jack mackerel harvested by recreational fishers by Fishstock and survey, the corresponding estimated survey harvest, and the estimated Fishstock harvest. Surveys were carried out in different years in Ministry of Fisheries regions: South in 1991–92, Central in 1992–93, North in 1993–94, and National in 1996. Estimates of *cv* and harvest tonnages are not presented where sample sizes are considered too small. The mean weight (284 g) used to convert numbers to catch weight, was calculated using data from national boatramp surveys, and is considered the best available estimate, but could be in error. Survey tonnages are presented as a range to reflect the uncertainty in the estimate. (Source: Bradford 1998)

		Total		Tonnage	
Fishstock	**Survey**	**Number**	***c.v.***	**Survey harvest**	**Point estimate**
JMA 1	North	350 000	12	70–140	105
JMA 7	North	16 000	30	4–12	8
JMA1	National	79 000	16	15–30	22
JMA3	National	<500	–	–	–
JMA7	National	21 000	–	–	–

Table 10 — *Continued*

Year	Month	JMD	JMM	JMN
1993	04	NA	NA	NA
1993	05	NA	NA	NA
1993	06	0	1	0
1993	08	0	1	0
1993	10	0.18	0.16	0.65
1993	11	0.64	0	0.36
1993	12	0.69	0.05	0.27
1994	01	0.54	0.07	0.39
1994	02	0.32	0.26	0.42
1994	03	NA	NA	NA
1994	04	NA	NA	NA
1994	05	0.33	0.24	0.43
1994	06	0.11	0.89	0
1994	07	0.08	0.92	0
1994	08	0	1	0
1994	09	0.65	0.35	0
1994	12	0.32	0.36	0.33
1995	01	0.31	0.22	0.47
1995	02	NA	NA	NA
1995	03	0.29	0.5	0.21
1995	04	NA	NA	NA
1995	05	NA	NA	NA
1995	07	0.06	0.94	0
1995	12	NA	NA	NA
1996	01	NA	NA	NA
1996	02	0.39	0.22	0.39
1996	03	0.56	0.21	0.23
1996	04	NA	NA	NA
1996	05	NA	NA	NA
1996	06	0	1	0
1996	08	0.05	0.95	0
1996	12	0.66	0.07	0.27
1997	01	0.59	0.07	0.34
1997	02	0.64	0.06	0.3
1997	03	0.51	0.22	0.26
1997	04	NA	NA	NA
1997	05	NA	NA	NA
1997	06	0.53	0.47	0
1997	07	0.09	0.91	0
1997	08	0.1	0.9	0
1997	09	0.08	0.92	0

Table 10: Species proportions estimated from scientific observer data for the three *Trachurus* species in JMA 7, by year and month; JMD is *T. declivis*, JMM is *T. symmetricus murphyi*, and JMN is *T. novaezelandiae*

Year	Month	JMD	JMM	JMN
1986	09	0.68	0	0.32
1986	11	0.65	0	0.35
1986	12	0.57	0	0.43
1987	01	0.54	0	0.46
1987	03	NA	NA	NA
1987	04	0.08	0	0.92
1987	05	0.31	0	0.69
1987	06	NA	NA	NA
1987	11	0.99	0	0.01
1988	01	0.52	0	0.48
1988	02	0.92	0	0.08
1988	03	0.32	0	0.68
1988	12	0.53	0	0.47
1989	02	NA	NA	NA
1989	08	0.97	0.03	0
1989	09	0.74	0.18	0.08
1989	10	0.48	0.2	0.32
1989	11	0.47	0	0.52
1989	12	0.13	0	0.87
1990	03	0.03	0	0.97
1990	04	0.1	0	0.9
1990	06	0.68	0	0.32
1990	10	NA	NA	NA
1990	12	0.67	0	0.33
1991	02	0.57	0.01	0.43
1991	03	0.47	0	0.52
1991	04	0.3	0	0.7
1991	05	0.28	0	0.71
1991	07	0.66	0.34	0
1991	08	0.17	0.83	0
1991	09	0.48	0.39	0.13
1991	10	0.48	0.02	0.5
1991	11	0.51	0.04	0.45
1991	12	0.4	0.04	0.56
1992	01	NA	NA	NA
1992	02	NA	NA	NA
1992	03	0.33	0.02	0.65
1992	04	NA	NA	NA
1992	05	0.86	0.07	0.07
1992	07	0.15	0.7	0.15
1992	08	0	1	0
1992	09	0.48	0.52	0
1992	10	0.84	0.16	0
1992	12	0.67	0.11	0.22
1993	01	0.61	0.14	0.25
1993	02	0.5	0.21	0.3
1993	03	0.68	0.05	0.28

Table 11: Proportions of the three jack mackerels by year and quarter in the JMA 7 TCEPR landings, estimated from scientific observer data; shaded records are where there were missing data—values were interpolated as the mean of the values for the quarter preceding and following; JMD is *T. declivis*, JMM is *T. symmetricus murphyi*, and JMN is *T. novaezelandiae*

Year	Quarter	JMD	JMM	JMN
1989	3	0.76	0.16	0.08
1989	4	0.47	0.01	0.52
1990	1	0.03	0	0.97
1990	2	0.11	0	0.89
1990	3	0.39	0	0.61
1990	4	0.67	0	0.33
1991	1	0.49	0	0.51
1991	2	0.29	0	0.7
1991	3	0.46	0.48	0.06
1991	4	0.47	0.04	0.49
1992	1	0.33	0.02	0.65
1992	2	0.86	0.07	0.07
1992	3	0.29	0.66	0.05
1992	4	0.69	0.11	0.2
1993	1	0.55	0.17	0.27
1993	2	0	1	0
1993	3	0	1	0
1993	4	0.58	0.03	0.38
1994	1	0.41	0.18	0.4
1994	2	0.26	0.44	0.3
1994	3	0.14	0.86	0
1994	4	0.32	0.36	0.33
1995	1	0.30	0.33	0.37
1995	2	0.18	0.64	0.26
1995	3	0.06	0.94	0
1995	4	0.27	0.58	0.15
1996	1	0.47	0.22	0.31
1996	2	0	1	0
1996	3	0.05	0.95	0
1996	4	0.66	0.07	0.27
1997	1	0.61	0.07	0.32
1997	2	0.53	0.47	0
1997	3	0.08	0.92	0

Table 12a: Quarterly CVs for tow proportions of *Trachurus* species in observer data from JMA 7; *n* is the number of tows sampled, JMD is *T. declivis*, JMM is *T. symmetricus murphyi*, and JMN is *T. novaezelandiae*

Year	Quarter	JMD	JMM	JMN	*n*
1989	3	0.11	0.39	0.84	10
1989	4	0.11	NA	0.18	18
1990	1	0.42	NA	0.01	16
1990	2	0.20	NA	0.06	14
1990	3	NA	NA	NA	NA
1990	4	0.08	0.37	0.09	84
1991	1	0.08	0.39	0.07	66
1991	2	0.07	0.95	0.03	109
1991	3	0.18	0.17	0.55	24
1991	4	0.39	0.66	0.50	9
1992	1	0.19	0.38	0.15	46
1992	2	0.21	0.52	0.99	12
1992	3	0.23	0.26	0.43	18
1992	4	0.09	0.24	0.11	61
1993	1	0.07	0.06	0.09	173
1993	2	0.29	0.04	0.99	59
1993	3	NA	NA	NA	*1
1993	4	0.05	0.19	0.15	73
1994	1	0.12	0.11	0.12	70
1994	2	0.12	0.13	0.15	61
1994	3	0.33	0.06	NA	29
1994	4	0.11	0.43	0.14	73
1995	1	0.06	0.08	0.07	138
1995	2	0.84	0.07	NA	4
1995	3	NA	NA	NA	*1
1995	4	0.14	0.22	0.23	19
1996	1	0.10	0.08	0.13	101
1996	2	0.NA	0.32	NA	52
1996	3	0.61	0.02	NA	4
1996	4	0.19	0.54	0.22	8
1997	1	0.04	0.17	0.07	104
1997	2	0.30	0.12	NA	17
1997	3	0.20	0.02	NA	20

Table 12b: Annual CVs for tow proportions of *Trachurus* species in the observer data from JMA 7; *n* is the number of tows sampled, JMD is *T. declivis*, JMM is *T. symmetricus murphyi*, and JMN is *T. novaezelandiae*

Fishing year	JMD	JMM	JMN	*n*
1988–89	0.09	0.43	0.2	29
1989–90	0.08	0.36	0.06	114
1990–91	0.05	0.19	0.04	208
1991–92	0.08	0.16	0.1	137
1992–93	0.05	0.05	0.08	288
1993–94	0.07	0.07	0.09	233
1994–95	0.05	0.07	0.07	162
1995–96	0.1	0.04	0.14	165
1996–97	0.05	0.09	0.07	149

Table 13: Summary of life history parameters for *T. declivis* and *T. novaezelandiae* and their sources. Horn (1991a) recorded no difference between males & females. For definitions of parameters, see Francis (1990); JMD is *T. declivis* and JMN is *T. novaezelandiae*

Parameter	JMD	JMN	Source
M	0.18	0.18	Horn 1991a
L_∞	46 cm	36 cm	Horn 1991a
k	0.28	0.30	Horn 1991a
t_0	- 0.40	- 0.65	Horn 1991a
a	0.023	0.028	Horn 1991a
b	2.84	2.84	Horn 1991a
h	0.924	0.924	Myers *et al.* 1995
A_m	3 yrs	4 yrs	Horn 1991a
A_r	4 yrs	7 yrs	Horn 1991a

M: Natural mortality
L_∞, k, t_0 : Von Bertalanffy growth parameters
a & b : length–weight parameters
h: 'steepness' for the Beverton and Holt stock-recruitment relationship—estimated as mean of the values marked * in Table 14
A_m & A_r : ages at maturity and recruitment

Table 14: Values of "steepness" (*h*) for the Beverton and Holt stock-recruitment relationship for members of the Order Perciformes, from data and using methodology presented by Myers *et al.* (1995)

Family	Species	Area	h
Ammodytidae	*Ammodytes marinus*	Northern North Sea	0.99
		Shetland	0.57
		Southern North Sea	0.42
		ICES Via	0.58
Carangidae	*Trachurus capensis*	South Africa	*1.01
	Trachurus trachurus	Western ICES	*0.62
		ICES VIIIc & IXa	*0.99
Lactariidae	*Lactarius lactarius*	Gulf of Thailand	0.43
Lutjanidae	*Lutjanus synagris*	Cuba – Zone B	0.61
Mugilidae	*Mugil cephalus*	Taiwan	0.20
Scombridae	*Scomber japonicus*	Southern California	*1.00
	Scomber scombrus	NAFO 2–6	0.35
		Western ICES	*1.00
	Thunnus albacares	Eastern Pacific Ocean	0.55
	Thunnus maccoyii	Pacific Ocean	0.42
Sparidae	*Taius tumifrons*	East China Sea	0.99

*Values of *h* for *T. declivis* & *T. novaezelandiae* were estimated as the mean of these values

Table 15: Annual species proportions used in determining catch histories; JMD is *T. declivis*, JMM is *T. symmetricus murphyi*, and JMN is *T. novaezelandiae*

Year	JMD	JMM	JMN
1981–82 †	0.44	–	0.56
1982–83 ‡	0.56	–	0.44
1985–86 *	0.68	0.00	0.32
1986–87 *	0.58	0.00	0.42
1987–88 *	0.58	0.00	0.42
1988–89 *	0.63	0.07	0.30
1989–90 *	0.29	0.01	0.70
1990–91 *	0.38	0.03	0.60
1991–92 *	0.46	0.09	0.45
1992–93 *	0.59	0.17	0.25
1993–94 *	0.35	0.38	0.27
1994–95 *	0.30	0.34	0.36
1995–96 *	0.36	0.41	0.23
1996–97 *	0.58	0.15	0.27

* Source—estimated using scientific observer data; applied to specified years of catch histories

† Source—estimated from data in Robertson *et al.* (1989); applied to years of catch histories between 1946 and 1981–82 inclusive

‡ Source—mean of the 1981–82 and 1985–86 estimates; applied to years of catch histories between 1 1982–83 and 1984–85 inclusive

Table 16: Summary of variables used in standardising the CPUE stock indices

Variable name	Name_2	Type	Description
Year	Yr	Categorical	Calendar year of tow
Month	mt	Categorical	Calendar month of tow
Latitude †	lt	Continuous	Latitude of start of tow
Longitude †	lg	Continuous	Longitude of start of tow
Moonphase †‡	ph	Continuous	Relative light intensity
Bycatch	bct	Continuous	Catch of other species in the tow(t)
Bottom depth	btd	Continuous	Depth at tow start (m)
Vessel speed	spd	Continuous	Speed of vessel at tow start (knots)
Vessel nation	ntn	Categorical	Country of vessel flag
Age of vessel	age	Categorical	1998 minus year vessel was built
Vessel crew number	crw	Continuous	Number of crew on vessel
Vessel power	kwt	Continuous	Engine power of vessel (kwts)
Vessel length	lgt	Continuous	Length overall of vessel (m)
Vessel breadth	brd	Continuous	Breadth of vessel (m)
Vessel draught	drt	Continuous	Draught of vessel (m)
Vessel tonnage	ton	Continuous	Gross tonnage of vessel (t)
Vessel length*breadth*draught	vol	Continuous	Total volume of vessel (m^3)
Gear	gr	Categorical	Net type used for tow (midwater or bottom trawl)
Wingspread	wg	Continuous	Wingspread of gear (m)
Headline height	hdl	Continuous	Height of headline (m)
Gear relative depth	rdp	Continuous	Bottom depth minus gear depth (m)
Finish time	tmf	Continuous	Time tow completed (24 hr clock)

‡ The moonphase data series was generated using the routine 'Xphoon' which provides moonphase data for bitmaps within the 'X' windows environment, written by John Walker (Release 2).
All other variables are from MFish catch and effort and MFish vessel-information databases.
† Included for input to the model as 1st, 2nd, 3rd, and 4th order polynomial

Table 17: Summary of the final model for each CPUE series and fishery (summer, winter, & the two combined), including variable lists in their order of inclusion, cumulative values for R^2 (%), and p values from the analysis of variance (significance defined as $p < 10^{-5}$)

Series	Fishery & statistics	Variables in order of their inclusion into the model*											
CPUE$_1$	Summer	Yr	kwt	tmf	mt	lg^4	lt^4	bct	ton	ntn	hdl	wg	age
	R^2	1	6	7	10	12	12	13	13	14	15	15	16
	p value	0	0	0	0	0	10^{-11}	10^{-11}	10^{-9}	0	10^{-14}	10^{-14}	10^{-7}
	Winter	Yr	ntn	mt	lt^4	tmf	spd	lg^4					
	R^2	3	15	17	19	19	20	21					
	p value	0	0	0	0	10^{-9}	0	10^{-7}					
	Combined	Yr	ton	mt	tmf	brd	lg^3						
	R^2	1	8	12	13	14	15						
	p value	0	0	0	0	0	0						
CPUE$_2$	Summer	Yr	mt	ntn	lg^2	wg	hdl	lbd					
	R^2	16	39	41	42	43	43	45					
	p value	0	0	0	0	0	0	0					
	Winter	Yr	mt	ntn	lt^4								
	R^2	46	54	55	56								
	p value	0	0	0	0								
	Combined	Yr	mt	lg^4	ntn	lbd	drt						
	R^2	26	43	43	44	44	45						
	p value	0	0	0	0	0	0						
CPUE$_3$	Summer	Yr	mt	ntn	crw	lg^2	wg	hdl	lbd				
	R^2	16	36	39	41	42	42	43	44				
	p value	0	0	0	0	0	0	0	0				
	Winter	Yr	mt	ntn	lt^4	tmf	hdl						
	R^2	45	53	54	55	55	56						
	p value	0	0	0	0	10^{-6}	10^{-11}						
	Combined	Yr	mt	ntn	lbd	lg^4	drt	tmf					
	R^2	14	20	23	24	25	26	27					
	p value	0	0	0	0	0	0	0					
CPUE$_4$	Summer	Yr	mt	crw	ntn	spd	wg	gr	lbd	lg^2			
	R^2	23	51	51	53	53	54	55	55	56			
	p value	0	0	0	0	10^{-12}	0	0	0	0			
	Winter	Yr	mt	ntn									
	R^2	55	73	74									
	p value	0	0	0									
	Combined	Yr	mt	ntn									
	R^2	34	65	66									
	p value	0	0	0									

*Variable names are the same as "Name$_2$" in Table 16; Power functions indicate the order of polynomial fitted

CPUE$_1$: All species – *T. declivis*, *T. novaezelandiae*, and *T. symmetricus murphyi*

CPUE$_2$: *T. declivis* and *T. novaezelandiae*

CPUE$_3$: *T. declivis*

CPUE$_4$: *T. novaezelandiae*

Table 18: Summary of year effects for each CPUE series and fishery. Shaded rows were used as stock indices in the stock reduction model

Series	Fishery	1989	1990	1991	1992	1993	1994	1995	1996	1997
$CPUE_1$	Summer	1.00	0.71	0.81	0.72	0.60	0.56	0.59	0.65	0.93
	Winter	1.00	0.75	0.60	0.74	0.55	0.58	0.76	0.43	0.30
	Combined	1.00	0.64	0.81	0.78	0.67	0.62	0.73	0.61	0.60
$CPUE_2$	Summer	1.00	2.72	0.99	1.68	0.11	0.64	0.60	0.05	0.64
	Winter	1.00	1.91	1.23	0.77	0.00	0.55	0.99	0.00	0.39
	Combined	1.00	1.61	0.71	0.94	0.00	0.46	0.43	0.00	0.57
$CPUE_3$	Summer	1.00	0.73	1.48	3.61	0.20	1.04	0.97	0.10	5.37
	Winter	1.00	0.86	0.89	0.99	0.00	0.57	0.97	0.00	0.40
	Combined	1.00	0.37	0.66	0.87	0.34	0.43	0.39	0.31	0.59
$CPUE_4$	Summer	1.00	5.68	1.38	1.05	0.11	0.80	0.82	0.05	0.01
	Winter	1.00	6.30	0.70	0.30	0.00	0.01	0.02	0.00	0.00
	Combined	1.00	2.50	0.47	0.30	0.01	0.05	0.08	0.00	0.00

Table 19: Starting values of virgin recruitment (R_0) for the stock reduction model, and values for virgin biomass (B_0), R_0, and total sum of squares (*SS*) or total robust likelihood (*RL*) after the model had converged. *N* & *D* denote *Trachurus novaezelandiae* and *T. declivis* repectively. Series SS or RL denotes model runs minimising the total *SS* or *RL* respectively. Shaded rows indicate the lowest value test statistic and model outputs of B_0 and R_0 for the two species

	Starting values		Convergence values				
Series	R_0N	R_0D	B_0N	B_0D	R_0N	R_0D	*SS*
SS	10	10	57 463	178	16.9045	10.3203	220.9688
SS	12	12	426	953	12.0000	12.0000	238.0571
SS	14	14	3 611	67 934	14.1389	16.2670	229.0324
SS	16	16	6 495	67 933	14.7252	16.2670	229.0323
SS	17	17	57 463	67 933	16.9054	16.2670	211.9444
SS	18	18	57 463	67 929	16.9054	16.2669	211.9459
SS	20	20	57 463	2 045 102	16.9054	19.6717	220.9285
SS	25	25	57 464	186 556 842	16.9054	24.1850	220.9684
Series	R_0N	R_0D	B_0N	B_0D	R_0N	R_0D	*RL*
RL	10	10	57 463	95	16.9054	9.6970	124.3931
RL	12	12	426	953	12.0000	12.0000	125.6934
RL	14	14	3 145	7 039	14.0000	14.0000	125.6934
RL	16	16	57 463	572	16.9054	11.4896	124.3931
RL	17	17	57 464	246 305	16.9054	17.5550	124.3624
RL	18	18	57 463	240 247	16.9054	17.5301	124.3625
RL	20	20	57 463	241 046	16.9054	17.5335	124.3625
RL	25	25	57 463	157 634 711	16.9054	24.0165	124.3930

Table 20: Virgin cohort weights (kg) for *Trachurus declivis* and *T. novaezelandiae* in the JMA 7 TCEPR fishery showing peak weights at age 6 and 5 respectively; JMD is *T. declivis*, and JMN is *T. novaezelandiae*

Age (yr)	JMD	JMN
1	575 045	1 119 332
2	1 544 841	2 454 059
3	2 458 919	3 550 587
4	3 081 140	4 199 451
5	3 378 655	4 426 829
6	3 411 520	4 343 037
7	3 262 695	4 063 927
8	3 006 463	3 681 990
9	2 698 782	3 261 602
10	2 377 518	2 843 347
11	2 066 084	2 450 401
12	1 777 522	2 094 253
13	1 517 953	1 779 045
14	1 289 151	1 504 584
15	1 090 332	1 268 326
16	919 331	1 066 604
17	773 354	895 381
18	649 423	750 664
19	544 637	628 730
20	456 306	526 227
21	382 016	440 203
22	319 642	368 098
23	267 338	307 715
24	223 520	257 182
25	186 840	214 914
26	156 150	179 571
27	130 483	150 028

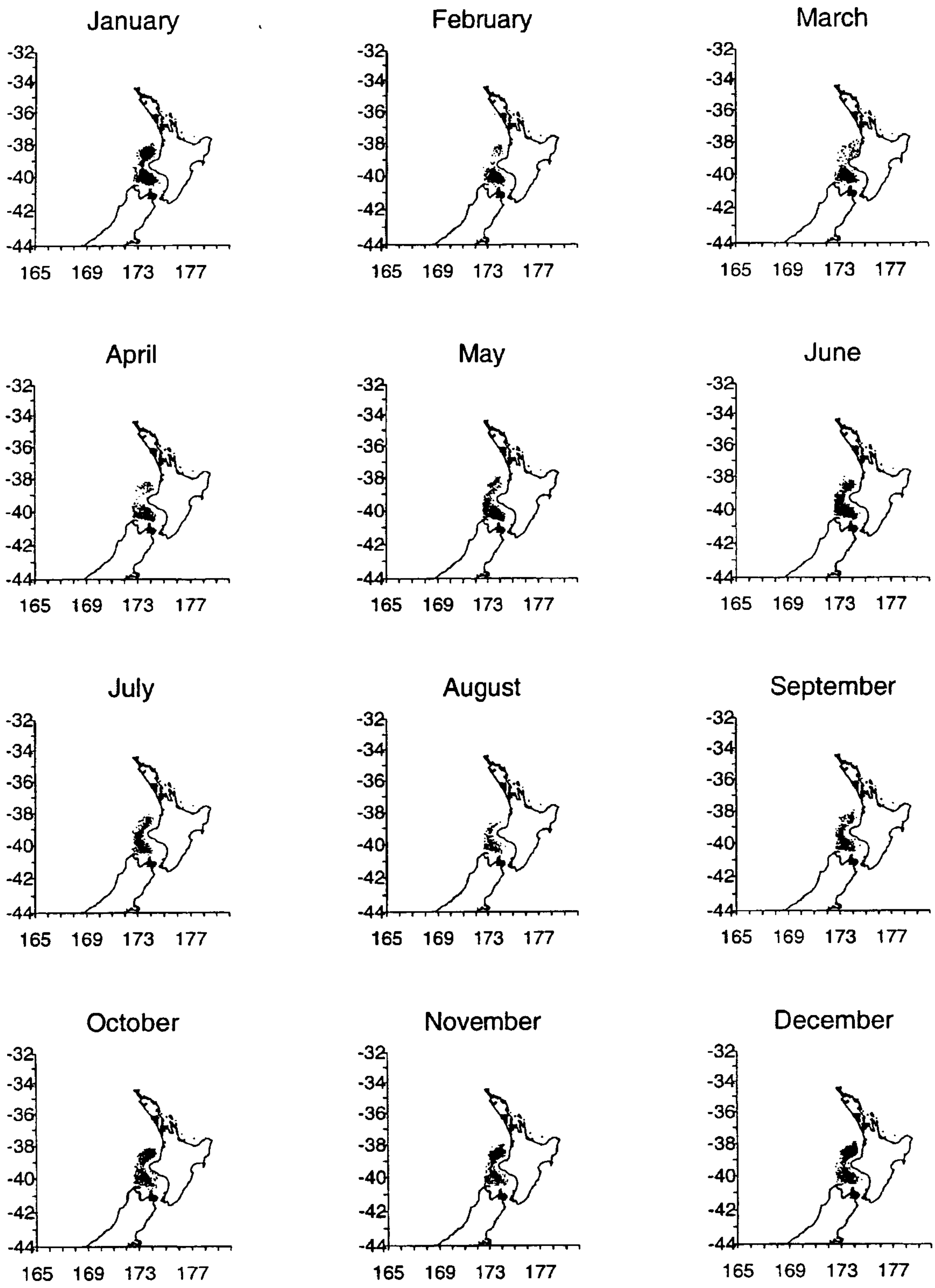


Figure 1a: Trawl positions by month (aggregated over all years, 1986–97) of tows in the JMA 7 TCEPR jack mackerel target fishery.

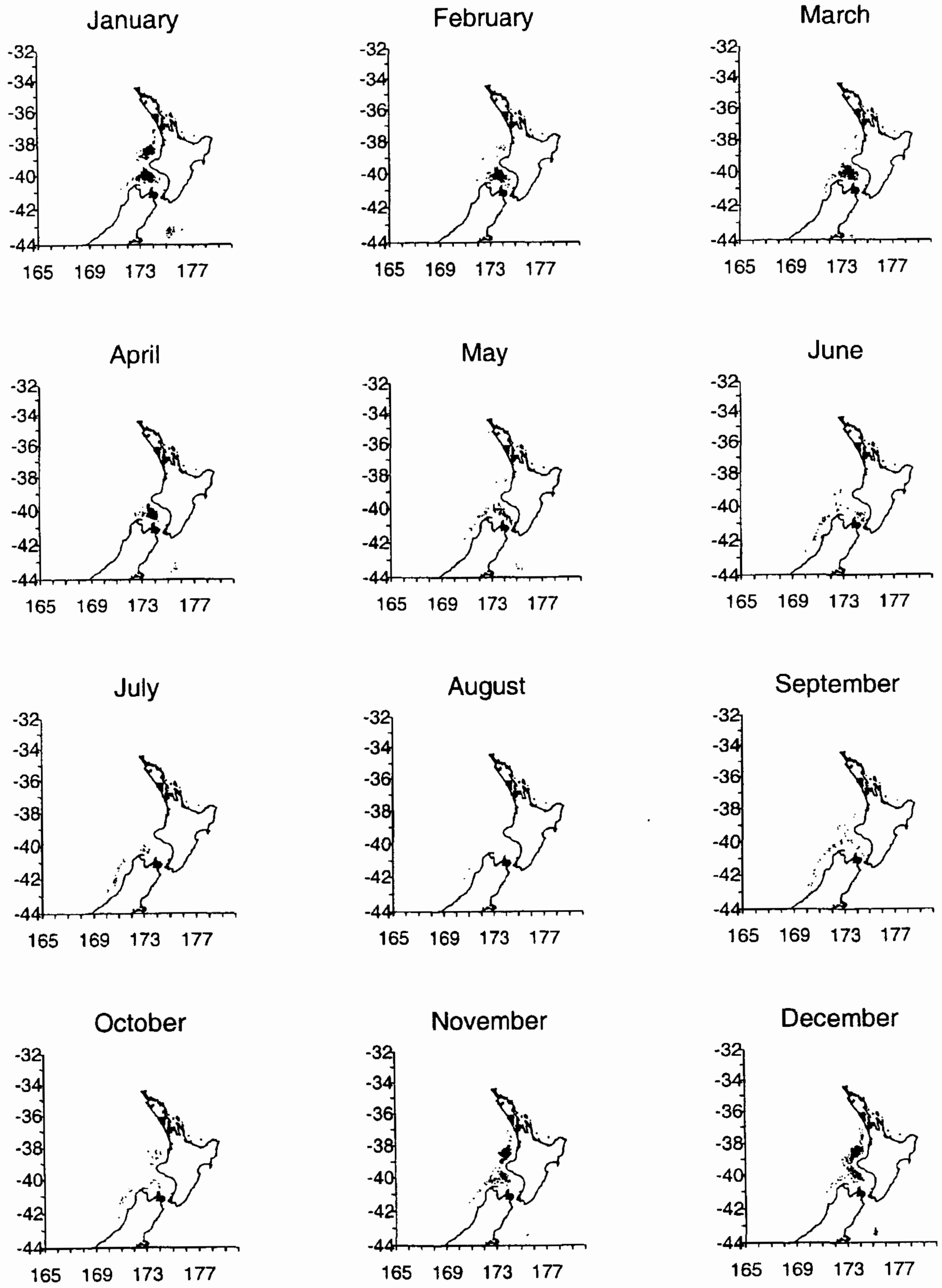


Figure 1b: Trawl positions by month (aggregated over all years, 1989–98) of tows sampled by scientific observers in the TCEPR jack mackerel target fishery.

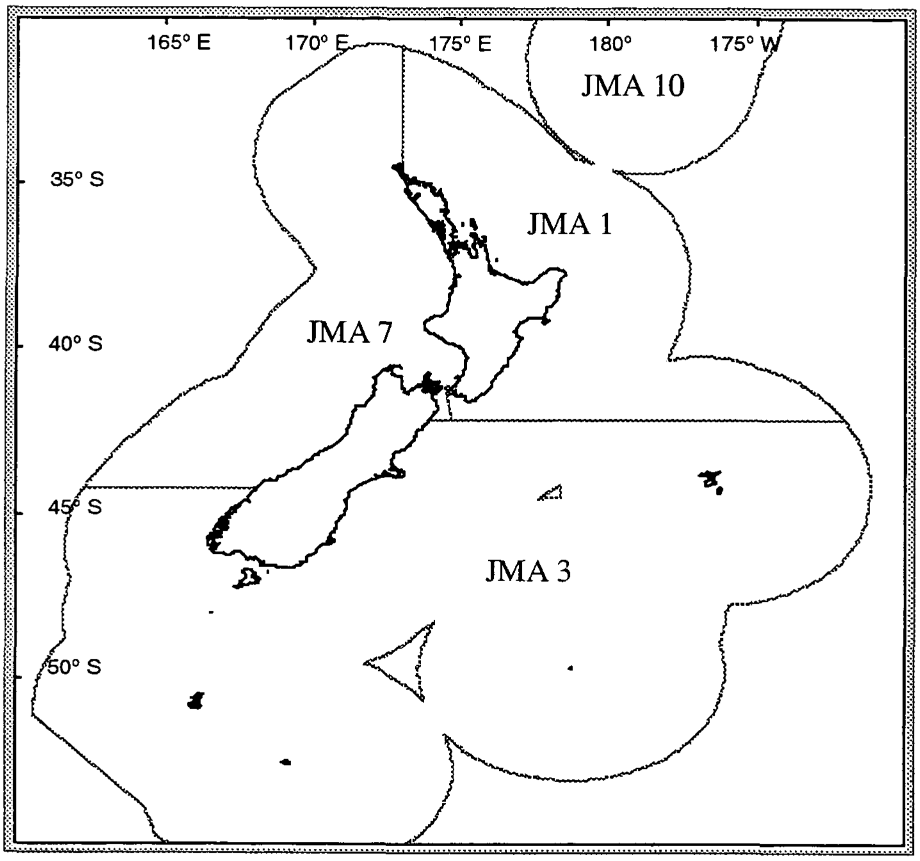
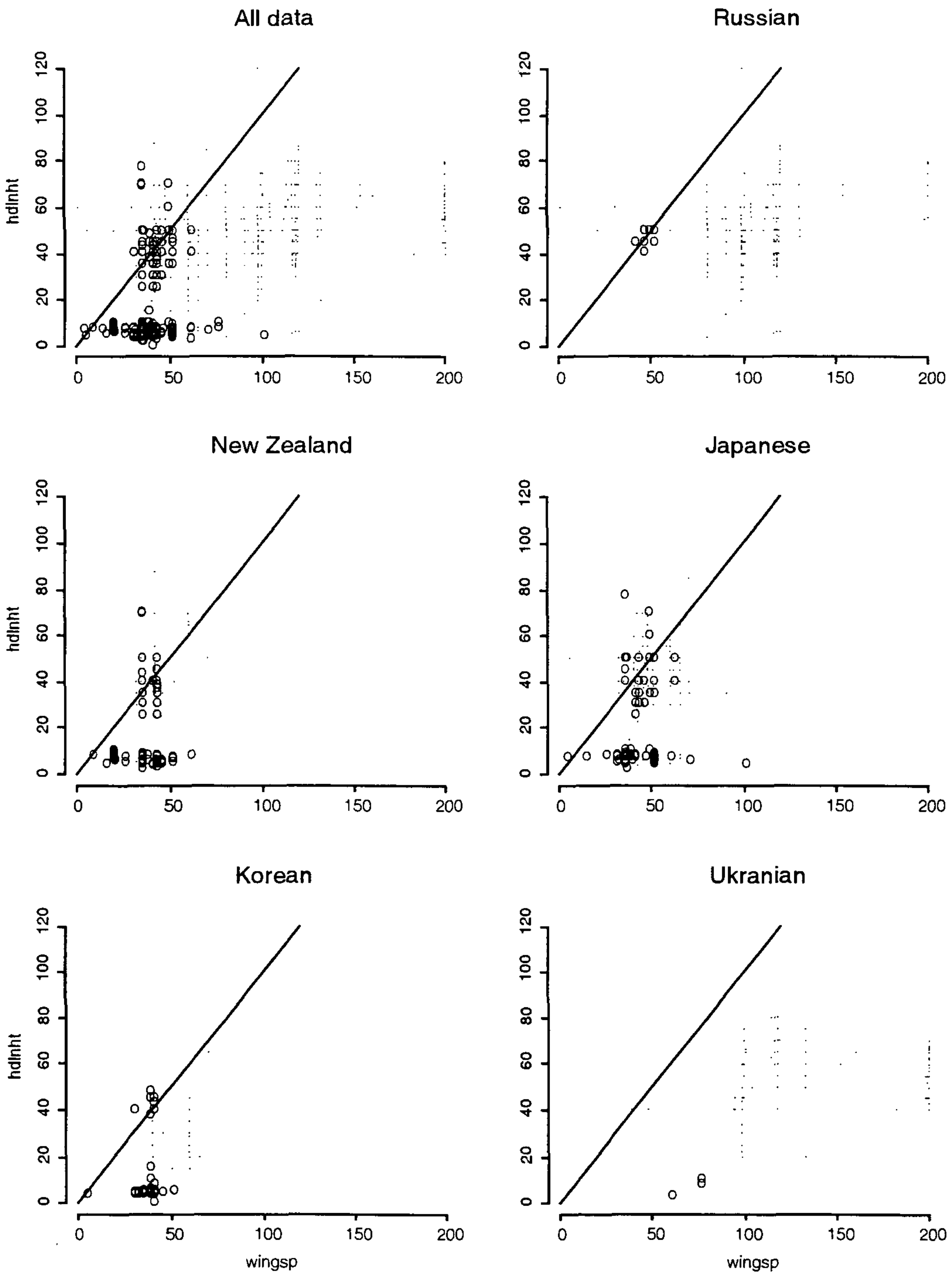


Figure 2: Jack mackerel Fishstocks.



All data

Russian

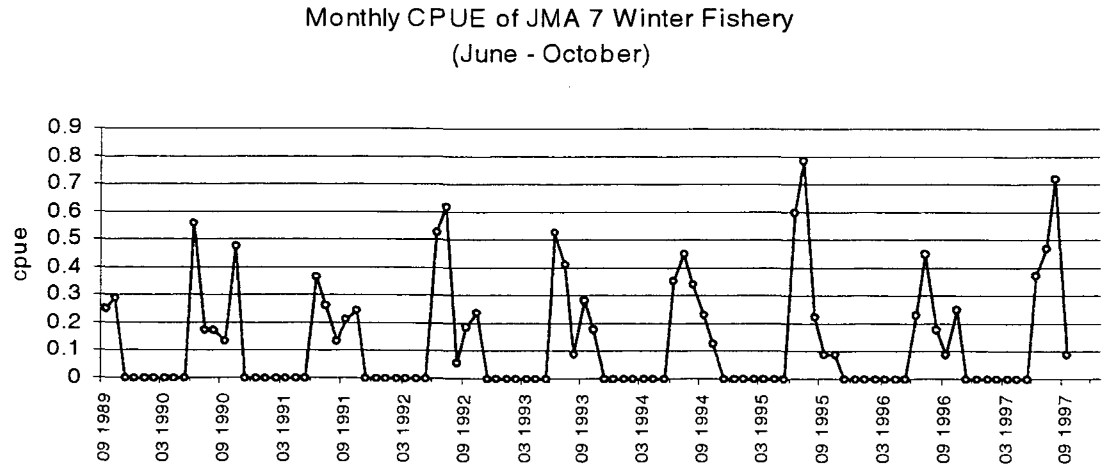
New Zealand

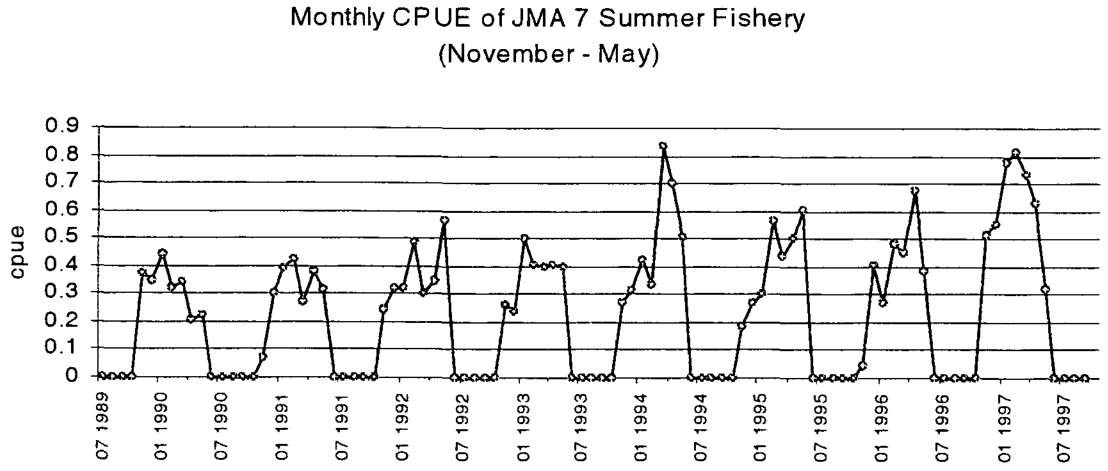
Japanese

Korean

Ukranian

Figure 3: Plots of headline-height on wingspread showing relationships of bottom (o) and midwater (.) trawl. (Source: MFish catch and effort database).





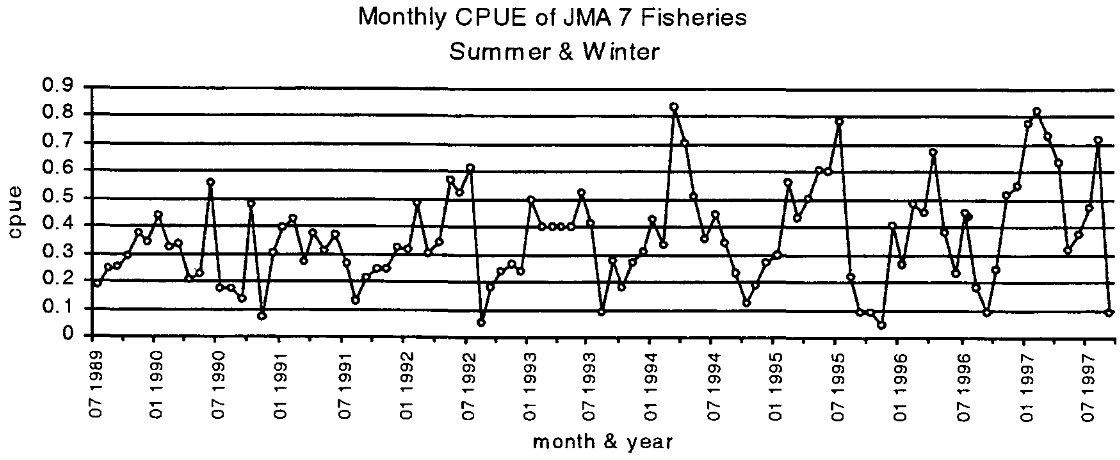
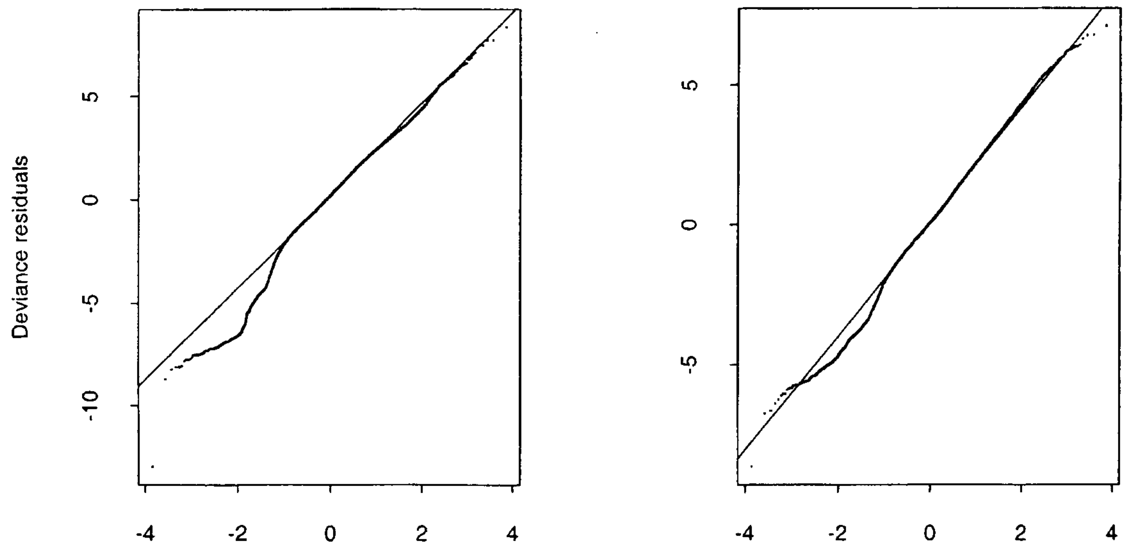
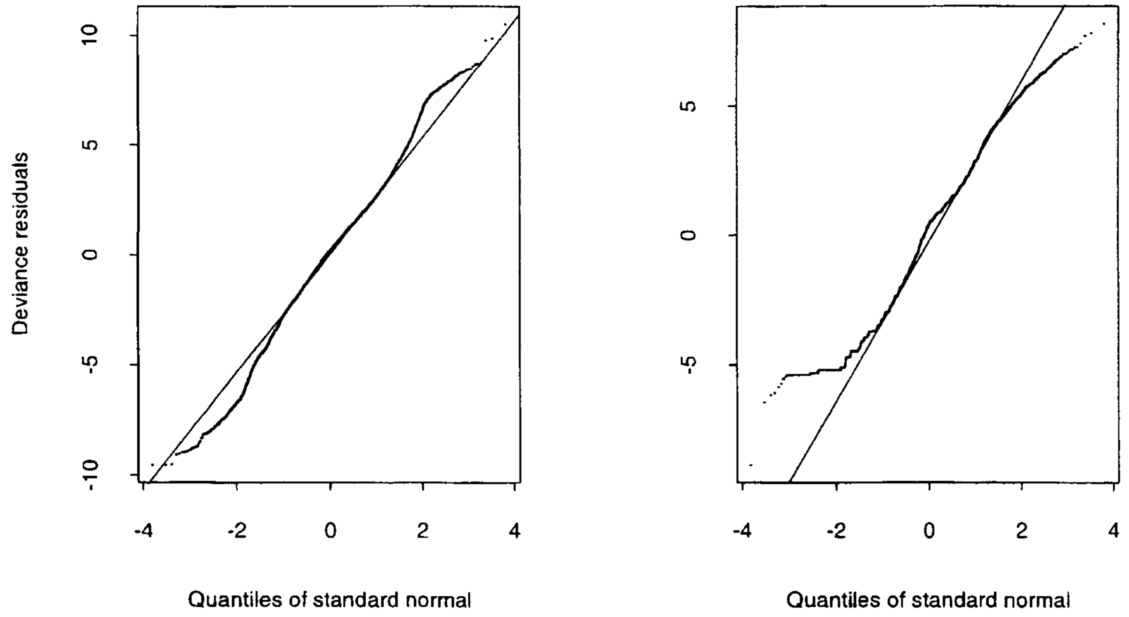


Figure 4: ***CPUE*** **series of the 'summer' and 'winter' fisheries in JMA 7, and the two combined.**


(a) JMD summer fishery

(b) JMN summer fishery


(c) JMD winter fishery

(d) JMN winter fishery

Figure 5: Plots of deviance residuals to examine their degree of normality; a & c refer to the fits to summer and winter *CPUE* series of *Trachurus declivis* (JMD), and b & d to the fits to summer and winter *CPUE* series of *T. novaezelandiae* (JMN).

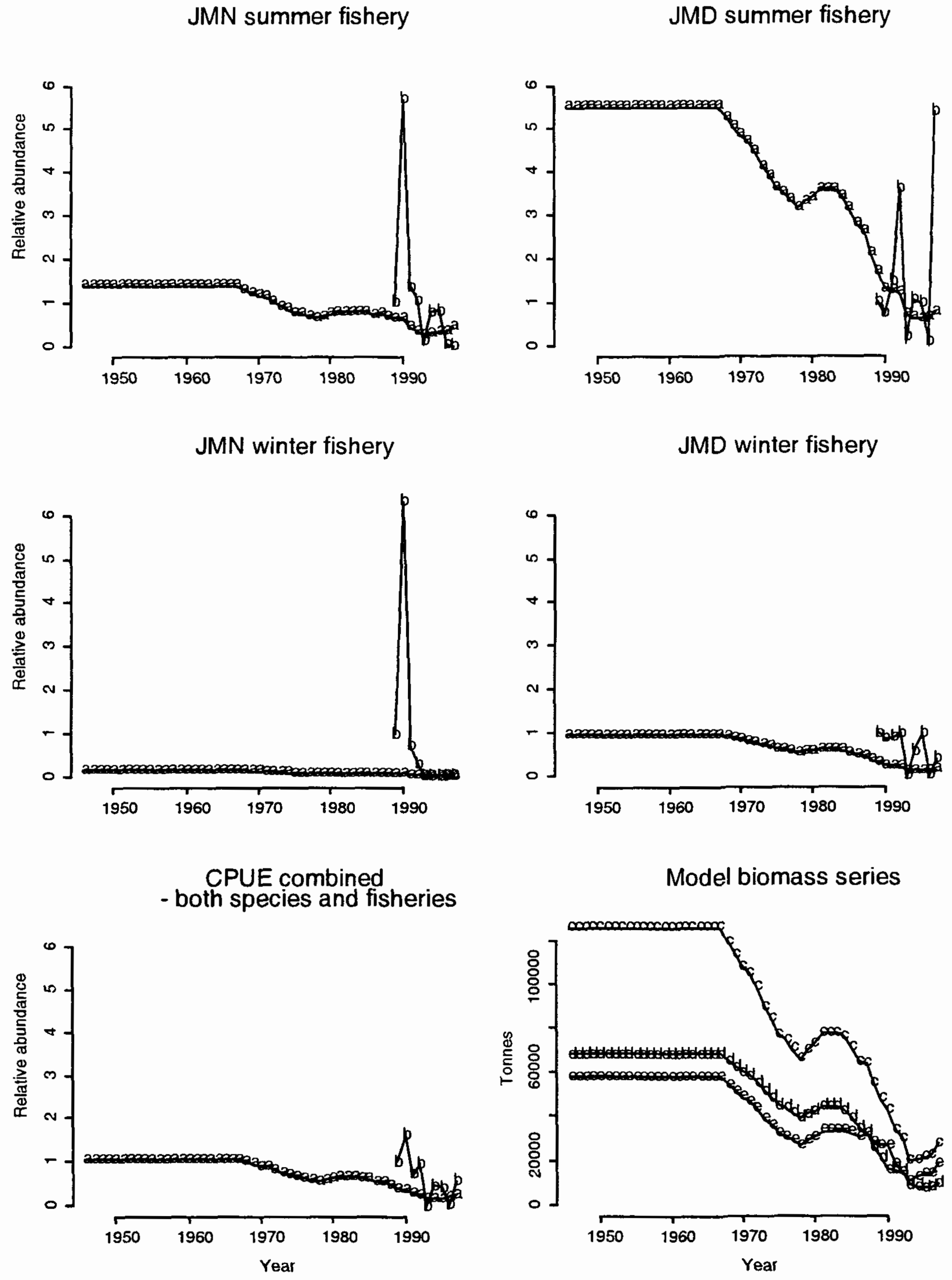


Figure 6: Predicted (plotting character a) and observed (plotting character b) stock indices for the summer and winter TCEPR fisheries for *Trachurus declivis* and *T. novaezelandiae* in JMA 7, and for all data combined, and estimated biomass series (c is total of both species, d is *T. novaezelandiae* and e is *T. declivis*) for JMA 7, from the model run minimising the sum of squares.

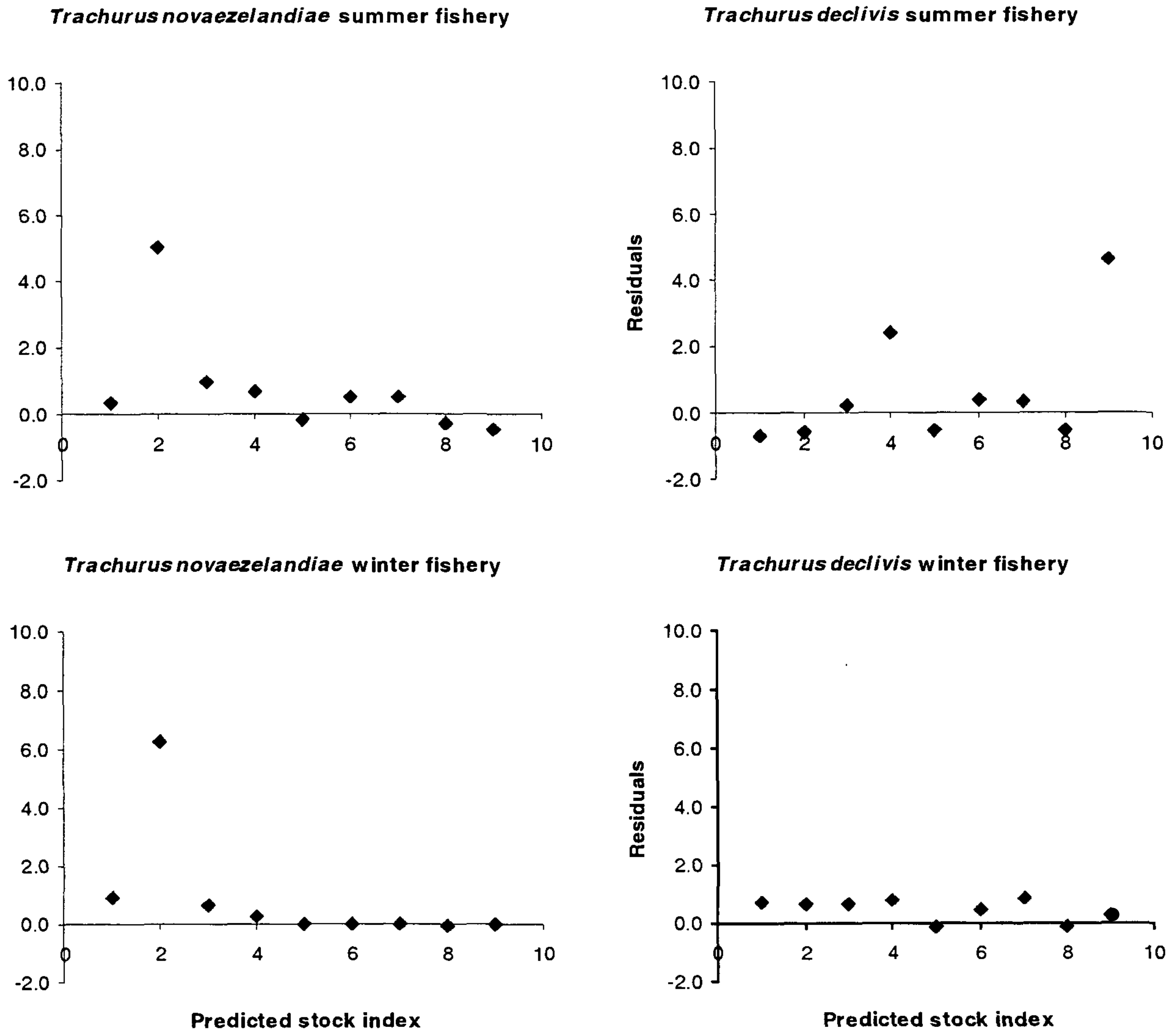


Figure 7: Residual plots of observed stock index (*CPUE*) minus predicted stock index for each of the four *CPUE* series used in the stock reduction model, from the model run minimising the sum of squares.

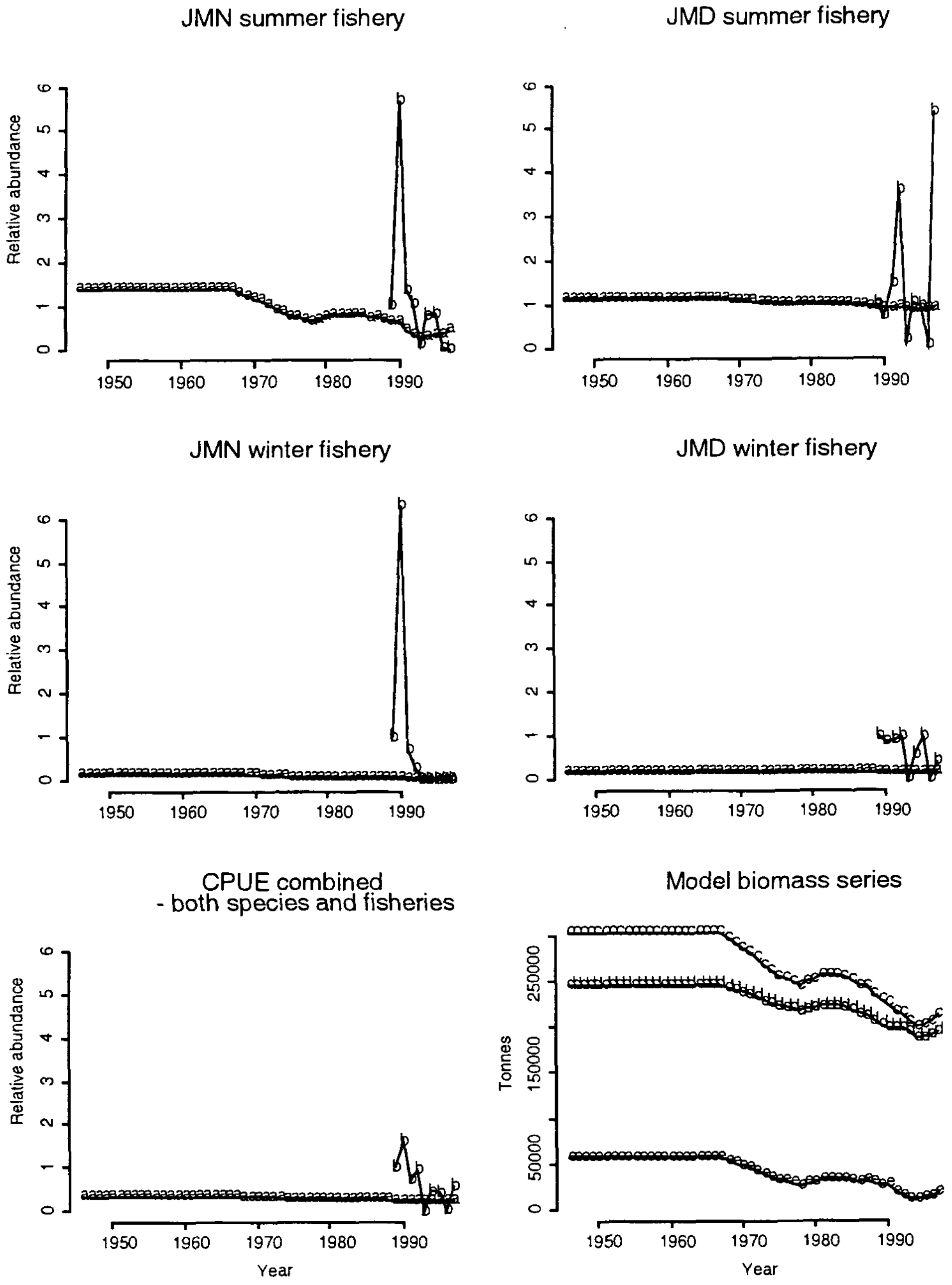
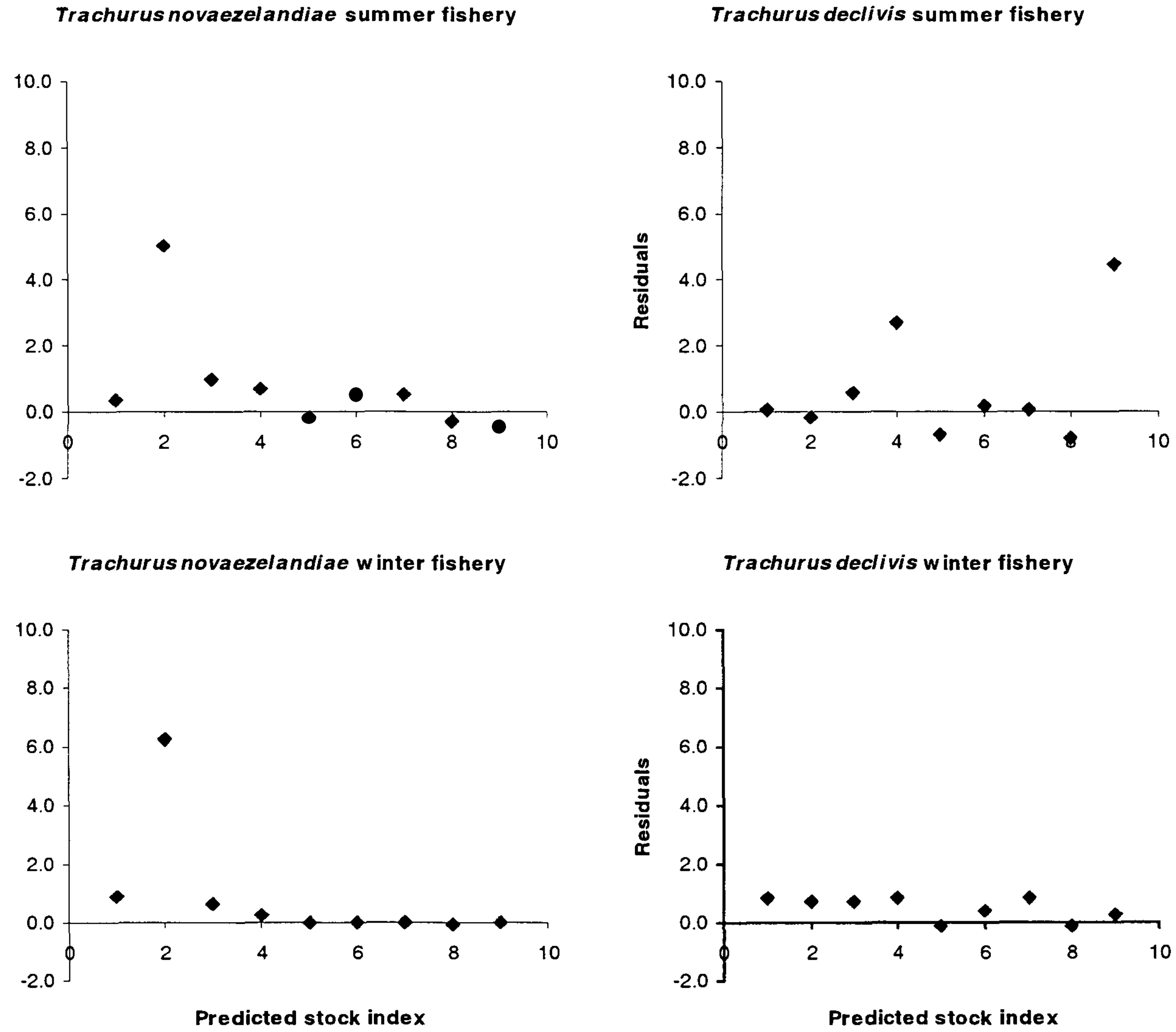


Figure 8: Predicted (plotting character a) and observed (plotting character b) stock indices for the summer and winter TCEPR fisheries for *Trachurus declivis* and *T. novaezelandiae* in JMA 7, and for all data combined, and estimated biomass series (c is total of both species, d is *T. novaezelandiae* and e is *T. declivis*) for JMA 7, from the model run minimising the robust likelihood estimate.


Trachurus novaezelandiae summer fishery

Trachurus declivis summer fishery

Trachurus novaezelandiae winter fishery

Trachurus declivis winter fishery

Figure 9: Residual plots of observed stock index (CPUE) minus predicted stock index for each of the four CPUE series used in the stock reduction model, from the model run minimising the robust likelihood estimate.

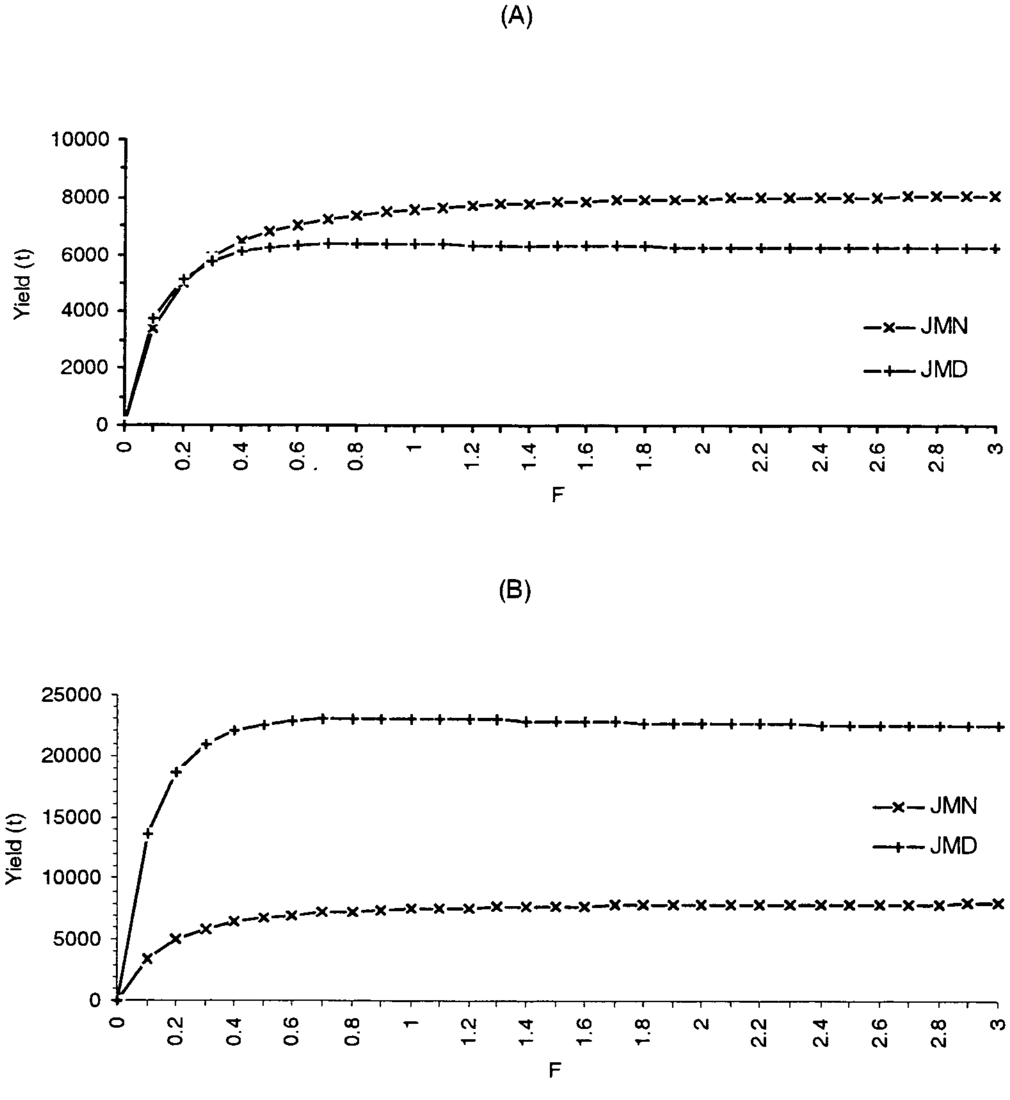


Figure 10: Yield per recruit curves for *Trachurus declivis* (JMD) and *T. novaezelandiae* (JMN) in the JMA 7 jack mackerel trawl fishery; based on B_0 values from (A) minimisation of the sum of squares and (B) minimisation of the robust likelihood estimator, and $F_{0.1}$ estimates of 0.7149 for *T. declivis* and 0.8999 for *T. novaezelandiae* in both cases.

Appendix 1: Estimating species proportions in the JMA 7 trawl fishery from observer data

Definitions

i	denotes species
j	denotes tows
k	denotes trips
S_k'	is the set of all tows in trip k, sampled and unsampled
S_k	is the set of sampled tows
w_{ijk}	is the weight of a sample of species i in sampled tow j during trip k
w_{jk}'	is the total weight of jack mackerel (both species combined) in sampled tow j during trip k
w_{jk}''	is the total weight of jack mackerel (both species combined) in the sample from sampled tow j during trip k

Estimating species proportions

The estimated proportion of species i in sampled tow j in trip k is

$$\hat{p}_{ijk} = w_{ijk} \big/ w_{jk}''$$

The estimated weight of species i in trip k, is obtained by scaling up the total weight of catch

$$\hat{W}_{ik}''' = \sum_{j \in S_k} w_{jk}' \hat{p}_{ijk} \cdot \frac{\sum_{j \in S_k'} w_{jk}'}{\sum_{j \in S_k} w_{jk}'}$$

The estimated proportion of species i in the total catch is obtained by summing over all trips

$$\hat{P}_i = \frac{\sum_k \hat{W}_{ik}'''}{\sum_i \sum_{j \in S_k'} w_{jk}'} .$$

Appendix 2: The age-structured population model

Definitions

$N_{i,k,s,y}$	number of fish of species i in age class k and sex s in year y
$R0_i$	recruitment of species i to the virgin population
S	annual finite survival rate (= exp(-M))
E_y	annual finite exploitation rate in year y
$v_{i,k,s}$	species age- and sex-specific vulnerability to the fishery
M	instantaneous natural mortality rate (assumed independent of age and year)
$L_{i,k,s}$	species age- and sex-specific length
$W_{i,k,s}$	species age- and sex-specific weight
C_y	observed catch in year y
$B_{i,y}$	model recruited biomass for species i in year y
$BS_{i,y}$	model spawning biomass for species i in year y
$B0_i$	virgin recruited biomass
$BS0_i$	virgin spawning biomass
q	catchability coefficient
$I_{y,obs}$	abundance index observed in year y
$I_{y,pred}$	abundance index predicted for year y
h	"steepness" of the stock-recruit relationship
α_i, β_i	parameters of the Beverton-Holt stock-recruitment curve for species i
$m_{i,k}$	species and age specific female mortality
F	instantaneous fishing mortality
$F_{0.1}$	is where the rate of change of yield with respect to F is 0.1 times that at the origin
$E_{0.1}$	exploitation rate resulting from $F_{0.1}$
$L\infty_i$	asymptotic length of species i
K_i	the growth rate towards maximum size for species i
t_{0i}	the point in time when fish of species i have zero length
a_i, b_i	parameters of the length-weight relationship for species i
SS	sum of squares of the residual differences between $I_{y,obs}$ with $I_{y,pre}$

Estimating numbers of fish

The number of fish in age class k in year y is calculated in terms of the previous year's numbers as:

$$N_{i,y,k,s}$$

$$\begin{cases} R0_i & \text{for } y = 1, k = 1 \\ N_{i,1,k-1,s}S = N_{1,t-1}e^{-M} & \text{for } y = 1, k > 1 \\ BS_{i,y-1}/\left(\alpha + \beta * BS_{y-1}\right) & \text{for } y > 1, k = 1 \\ N_{i,y-1,k-1,s}\left(1\text{-}E_{y-1}v_{k-1,s}\right)S & \text{for } y > 1, k > 1 \end{cases}$$

Exploitation rate in year y is given by

$$E_y = C_y / B_y .$$

The parameters α and β are given by

$$\alpha_i = (BS0_i(1-h))/(4hR_{0_i})$$

$$\beta_i = (5h-1)/(4hR_{0_i}).$$

They are non-biological parameters expressed in terms of R_0 and h under the assumption of a stable age distribution for the virgin biomass — *see* Francis (1992) for explanation.

Spawning biomass of species i in year y was defined as

$$BS_{i,y} = \sum_k (N_{i,y,k,female}) m_{i,k} . W_{,ki} / 1000 \qquad \text{for females}$$

Biomass estimation

The recruited biomass in year y is given by

$$B_y = \sum_i \sum_s \sum_k (N_{i,k,s} W_{i,k} v_{i,k})$$

where summation is over all species i, sexes s, and age classes k.

The mean weight of fish in age class k is derived by first estimating the mean length of fish in age class k using the von Bertalanffy mean length at age equation

$$L_{i,k} = L\infty_i \left(1 - e^{-k_i(t-t_0)}\right)$$

and then using the mean length at weight equation

$$W_{i,k} = a_i L_{i,k}^{b_i} .$$

Catchability estimation

Operation of the model was based on minimising the difference between the observed stock index (I_{obs}), and the predicted stock index (I_{pre}), which for year y is given by

$$I_{y,pre} = qB_y .$$

Estimation of the factor q, is a two stage process. The first step requires estimation of annual catchability for all species i included in the observed index, and sexes s in year y using

$$\hat{q}_y = I_{y,obs} / B_y .$$

Total catchability for all years is then given by

$$q = e^{\ln\left(\sum_y \hat{q}_y\right)/n}$$

where n is the number of years.

Minimising the sum of squares

A standard sum of squares of the residuals was used to minimise the difference between I_{obs} with I_{pre}, where the total sum of squares are given by

$$SS = \sum_y \left(I_{y,pred} - I_{y,obs}\right)^2 \qquad \text{if } I_{obs_y} > 0.$$

The model was run using the Microsoft Excel function "solver" to minimise the total sum of squares by changing the values of *R0i* for each species until convergence was met. A number of different starting values for *R0i* were tried until a reasonable fit was found, based on simultaneous time series plots of I_{obs} and I_{pre}, and time series plots of biomass estimated by the model.

Yield per recruit

An equilibrium situation was set up so that numbers of fish in age class k are estimated as

$$N_{i,k,s} = \begin{cases} RO_i & \text{for } k = 1 \\ N_{i,k-1,s}\left(1 - \left(E.v_{k-1,s}\right)\right)S & \text{for } k > 1 \end{cases}$$

This differs from the equation given above for the number of fish in age class k in year y, in that numbers for $y > 1$, $t > 1$ come from the previous age class in the *same year*.

Exploitation rate in year y is given by

$$E = \frac{Fref_i}{Fref_i + M}\left(1 - e^{-(-Fref_i + M)}\right)$$

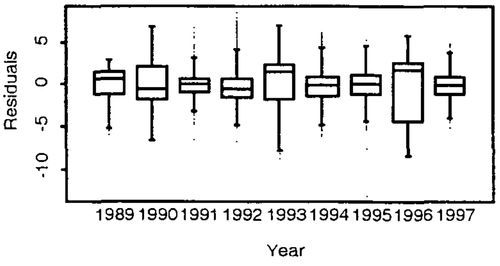
where *Fref* is the reference fishing mortality (Annala *et al.* 1998). *CAY* was estimated for each species using

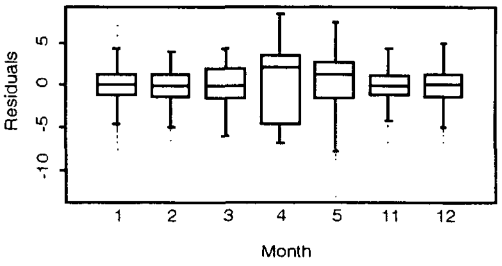
$$CAY = E_{0.1} B_{current}.$$

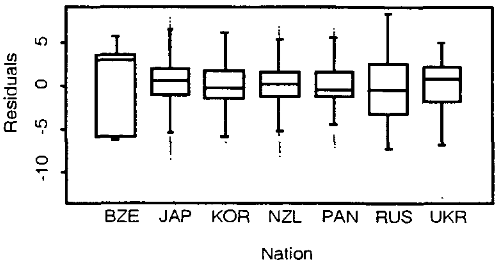
Appendix 3: Residual plots against a selection of predictor variables for each CPUE series

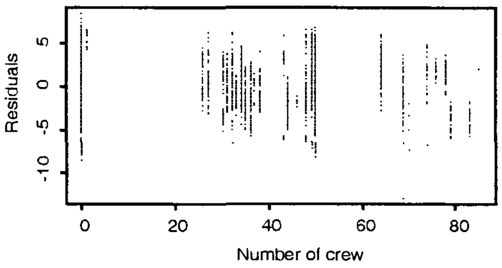
Abbreviations used in the plots: BZE is Belize, JAP is Japan, KOR is Korea, NZL is New Zealand, PAN is Republic of Panama, RUS is Russian Federation, and UKR is Ukraine; BT is bottom trawl, MW is midwater trawl.

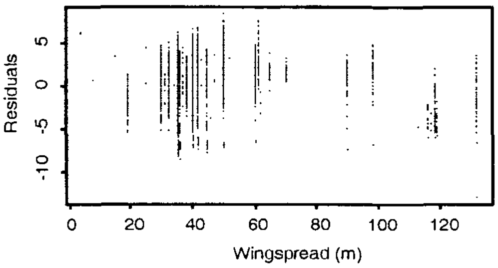
A) *Trachurus declivis* summer fishery

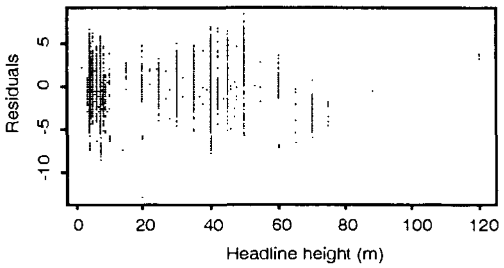


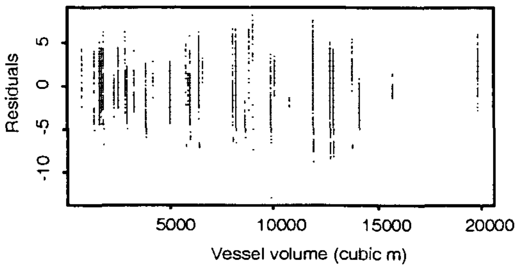






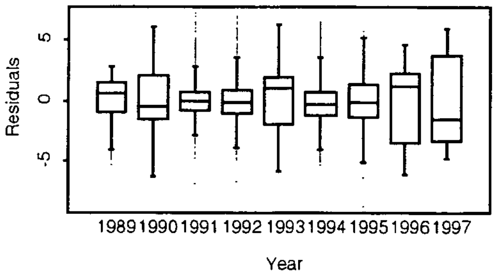


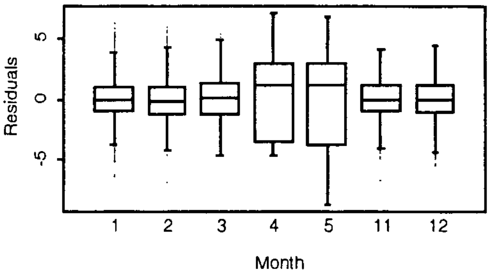


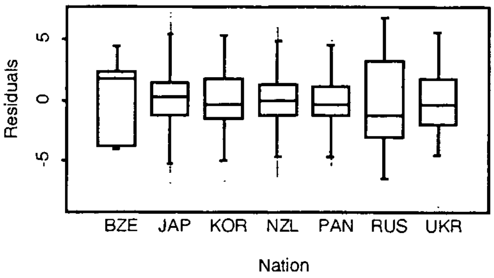


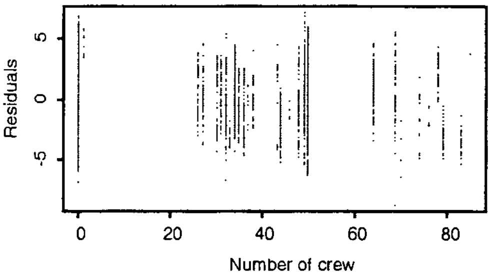
Appendix 3 — *continued*

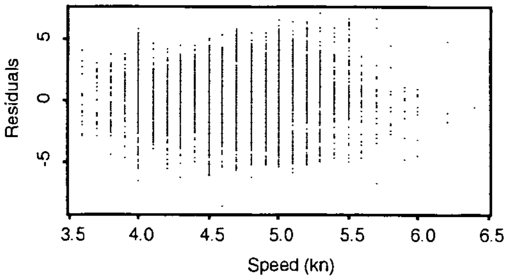
B) *T. novaezelandiae* summer fishery

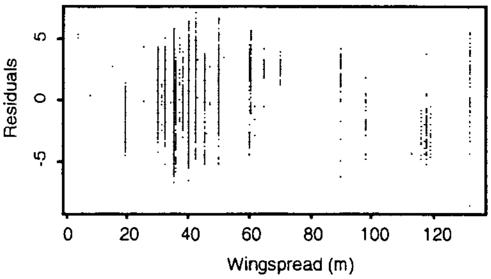


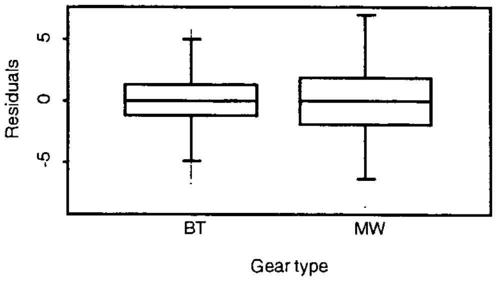


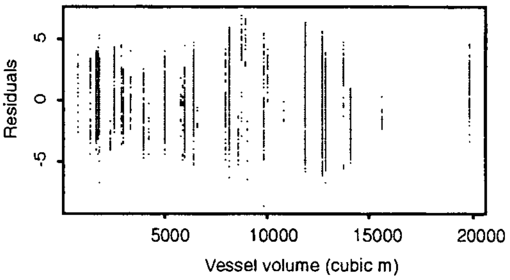






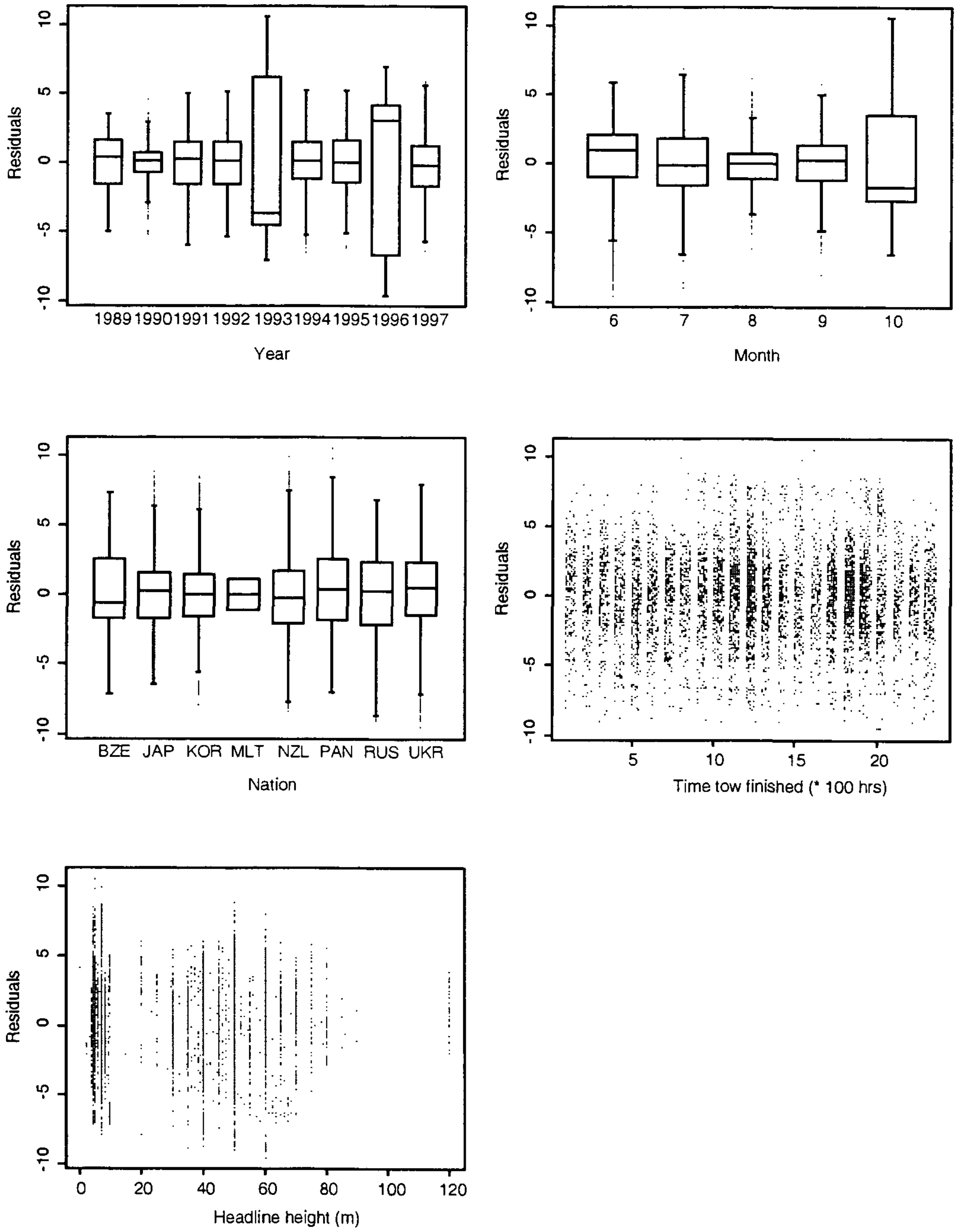






Appendix 3 — *continued*

C) *T. declivis* winter fishery



Appendix3 — *continued*

D) *T. novaezelandiae* winter fishery