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Standardised catch rate indices for New Zealand school shark, *Galeorhinus galeus*, 1989–90 to 1998–99

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EXECUTIVE SUMMARY

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This report addresses the Specific Objective: *To develop a standardised CPUE index for school shark* in Ministry of Fisheries project SCH1999/01 (Stock assessment of school shark).

New Zealand school shark have a patchy and changing distribution and are widely dispersed all around New Zealand. The total catch is small with a total allowable catch of 3107 t (since 1995–96), but it is caught by almost all fishing methods in almost all commercial fisheries, hence most vessels hold some school shark quota. Even the few vessels operating in the target fisheries move in and out of the fishery, and few vessels have consistently made a reasonable number of trips in all years and caught a reasonable quantity of school shark.

Standardised catch rate indices were estimated for target shark regional fisheries where there were adequate data available for the decade 1989–90 to 1998–99. The regional fisheries are loosely based on the school shark Fishstocks or QMA subdivisions of them. The most important change is the definition of a Cook Strait fishery that covers parts of several Fishstocks. The target set net shark fishery was originally defined as those sets where school shark or rig was the target species, but some rig-only vessels were removed to ease computational problems. The target bottom longline shark fishery was defined as those sets where school shark was the target species (rig are rarely caught on longlines). School shark bycatch of the ling longline fishery on the Chatham Rise was considered briefly.

Catch and effort data from both set net and bottom longline are recorded on Catch Effort Landing Returns (CELR) and data errors and confusions in interpretation of the catch and effort fields on these forms led to uncertainties in the raw data used in the analyses.

Incompatibilities between the current data recording system and earlier ones mean that producing indices including the years before 1989–90 is difficult.

The reviewers of the project tender required that several error distributions be tried in the standardisation. Many of the models tried failed on technical grounds, mainly due to the large numbers of zero and small catch rates and the high levels of "over-dispersion". The models that generally performed best were the delta-X models where the data are split into two parts, the zero (or small) catch rates and the rest. The two parts are treated separately and the resulting indices combined. The standardised catch rates estimated for the regional fisheries were different. They may not be good indices of catch rate because of data errors and the few vessels in the fishery and unbalanced data, and even if they were, they may not be good indices of abundance.

Sensitivity to the various assumptions made in the attempt to reduce the apparently erroneous data and to define the fishery has not been investigated. There is, however, no indication that the basic problems with the standardised indices would be resolved.

A single New Zealand-wide catch rate index was not developed due to uncertainties in the original data, uncertainties in the validity of the standardised regional catch rate indices, and lack of detailed knowledge of school shark stock structure and movements in New Zealand waters.

NIWA obtained the data from the industry log book scheme for the shark fishery. Brief analyses of some of these data are given to assist in understanding the fishery.

1. INTRODUCTION

School shark are caught throughout most of the New Zealand EEZ, including in deep water on tuna longlines. However, they appear more likely to be caught in waters out to 200 m depth or perhaps the shelf break (see, for example, Anderson et al. 1998, Bagley et al. 2000, Hurst et al. 2000). School shark probably spend most of the year in single sex schools of about the same size (Paul & Sanders 2001). Their size distributions appear to differ in different parts of New Zealand (Hurst et al. 1998).

The school shark fishery is small (TAC of 3107 t currently). School shark are caught by almost all commercial fishing methods, but predominantly by set net and bottom long line.

Paul & Sanders (2001) found that the number of vessels landing some school shark in a fishing year was about 800 (peaking at 891 in 1992–93) until the 1996–97 fishing year and has dropped slightly in the last two fishing years to 686 in 1998–99. The number of vessels using methods that might reasonably catch school shark increased from 1644 in 1989–90 to 1871 in 1992–93 and then dropped steadily to 1270 in 1998–99. That is, just over half the vessels using methods that might catch school shark actually caught some. Numbers of vessels using set netting and bottom long lining (the methods most likely to catch school shark) have shown patterns similar to the total number.

Over 1 t of school shark may be landed in a year when any of about 30 species was the designated target species, though about half the landings are made in trips where school shark was the target species (Paul & Sanders 2001). Only about five vessels have targeted school shark or caught more than 1 t of school shark for more than 10 days a year in each fishing year between 1989–90 to 1998–99 (Bradford & Paul, unpubl. results).

Over half the vessels targeting school shark do so on 5 days or less. In some areas of New Zealand, a higher than normal targeted school shark catch is taken in September, presumably by vessels wishing to fill their small school shark quota (held mainly to cover bycatch) at the end of the fishing year. An increase in school shark catch in September is not noticeable in the areas with the largest target fisheries (Paul & Sanders 2001).

The regression methods used to produce standardised indices work best with a balanced data set, that is, all levels of all factors used as explanatory variables have sufficient observations to be able to get a reliable average value. Individual vessels are likely to have different catch rates of school shark, and will be an important factor in the standardisations to be performed. A set of vessels staying in the fishery for a long period with reasonably consistent spatial/temporal fishing patterns is needed to determine reliable standardised catch rates. The discussion above should suggest that this is unlikely to be true and any standardised catch rate indices could be suspect.

The Australians have been working towards a reliable stock assessment of their school shark fishery over many years, starting with the production of a shark database that contains consistent and reliable data for more than 20 years (see Punt et al. 2000a, 2000b and references therein). Punt et al. (2000a) described the method they used to standardise the Australian school shark catch rates. We followed their methods, taking into account the reporting and fishery differences between New Zealand and Australia when developing standardised catch rate indices for New Zealand school shark. The only other related work found was a paper by Bigelow et al. (1999) who used generalised additive models to investigate the influence of environmental effects on swordfish and blue shark catch rates. We have no data suitable for such an investigation.

2. METHODS

2.1 Data available

The reporting forms used in New Zealand fisheries have changed several times. Ideally, we would like to use as long a data series as possible, certainly since the late 1970s when monofilament nets were introduced. The latter appears to be the last major gear change in the set net fishery. However, the analyses were restricted to data from the current collection system that started in 1989. The Fisheries Statistical Unit (FSU) collected fisheries data in New Zealand from 1983 until 1989. However, with the change to the Quota Management System (QMS) in 1986, reporting on FSU forms declined. FSU monthly summary data by vessel are available. Individual trip data have not yet been transferred from the original tapes to the Ministry of Fisheries database. No effort data are electronically available before 1983 on the Ministry of Fisheries database. However, some paper files of catch and effort data for the shark fishery before 1983 are available from the analysis of "the rig fishery (Francis & Smith 1988) and have been partially converted to electronic form at NIWA.

At the present time, catch and effort data for both set net and longline are submitted on Catch Effort Landing Returns (CELRs) and major problems were encountered due to the way these forms are formatted, how the required fields are described, and how fishers interpret the instructions (Bradford & Paul 2000). A consequence of these problems is that there is no guarantee that a catch rate estimated as catch divided by effort as recorded on the CELR forms bears any true relation to the actual catch rate.

The fishing methods that appear to be most likely to provide data that will be suitable for determining standardised catch indices for school shark are set netting and bottom long lining. Estimated catch and effort data for both of these methods are provided on CELR forms and are available for individual trips. The date of the start of the trip and a vessel identification key are available for essentially all trips. The vessel identification keys are a database construct and uniquely define each vessel.

Statistical area (available for most trips) is the only positional information available and there is no depth information. Hence it is impossible to detect any fine scale shifts over time.

The scoping study (Paul & Sanders 1998) suggested dividing the school shark fishery into several discrete regional fisheries based on statistical areas. These regional fisheries are largely related to the school shark Fishstocks or QMA subdivisions of them, except for the Cook Strait region that has statistical areas that lie within three Fishstocks. The definitions of the regions used extend and modify the definitions of the scoping study (Table 1, Figure 1).

The estimated catch is recorded on the CELR forms and is nominally a greenweight, but apparently estimated processed weight may be recorded instead; school sharks are usually processed at sea. Landed catch weights take into account the processed state and are expressed as green weights using the appropriate conversion factors but are amalgamated over several trips. For the vessels with higher catches, the ratio of total estimated catch to total landed catch in a year was used to scale the estimated catches for that vessel in that year.

For set netting, the effort variables provided are time of set, length of net set, and the mesh size. For longlining they are number of hooks, and number of sets. The instructions defining the effort part of the CELR forms were unclear in the past and fishers have interpreted them in different ways. Outlying and inconsistent values of effort variables have been modified though some of the changes made were subjective.

2.2 Definition of the fishery

For calculating standardised catch rates:

- the base case set net fishery was originally defined as being all sets where school shark or rig were the target species and the method was set net (but see Section 2.2.3);
- an alternative case for the set net fishery was defined as all trips where school shark was the target species and the method was set net;
- the bottom longline fishery was defined as all trips using bottom longlining and having school shark as the target species.

The effort variable was defined as kilometres of net set or thousands of hooks. The catch was measured in kilograms.

Table 2 contains the numbers of trips available in the above target fisheries in each region. Regional fisheries with fewer than 1000 trips are not considered further.

2.2.1 Zero catches

Zero school shark catches (and hence catch rates) mainly arise in the set net fishery when either school shark or rig were the target species and school shark was not listed amongst the top five species caught. The system of recording catch data means that one cannot differentiate between zero and very small catches of a species with any certainty. In some instances, the school shark catch was entered as zero in the database (and presumably given as zero on the form). NULL values of school shark catch were assumed to be zero catches. NULL values are not common and their assignment to zero should not lead to substantial biases.

2.2.2 Restrictions on catch rate

Some restrictions relating to catch rate were used. To eliminate trial or faulty sets, set net lengths had to be available and at least 350 m (Francis & Smith 1988). At least 100 hooks were needed to accept a longline set. To eliminate unrealistic catch rates all catch rates greater than 5000 kg per km or 10 000 kg per 1000 hooks were removed, and one very low catch rate was removed from the longline data. The latter arose from a catch of 1 and may have meant 1 fish rather than 1 kg.

2.2.3 Elimination of opportunistic and rig-only vessels

Some shark vessels exclusively, or primarily, catch rig, and others are vessels that opportunistically entered the fishery. Hence, all vessels fishing in a regional fishery that made 10 or fewer trips catching or targeting school shark, or that caught less than 1 t of school shark, between 1989–90 and 1998–99 were removed.

Table 2 shows how these restrictions modified the sizes of the data sets used in the analyses.

2.3 Standardisation of catch-effort

The catch-effort standardisation is carried out for the 10 fishing years available from the CELR data and for several of the regional fisheries, mainly for the set net data, but also for the target longline fishery in Cook Strait, and the ling bottom longline bycatch on the Chatham Rise. The standardisation is achieved by fitting a multiplicative model of the form described by Punt et al. (2000a):

$$\frac{C_{y,v,m,a}}{E_{y,v,m,a}} = e^{\mu+\alpha_y+\cdots} \quad \text{or} \quad C_{y,v,m,a} = e^{\mu+\alpha_y+\cdots} E_{y,v,m,a}$$

where

$C_{y,v,m,a}$	is the catch of school shark by vessel v in statistical area a in month m and fishing year y
$E_{y,v,m,a}$	is the effort expended by vessel v in statistical area a in month m and fishing year y
μ	is the global mean
α_y	is the factor for year y
...	means other factors that influence the catch

The variables that are included in the models are (where appropriate): fishing year; vessel; month; statistical area; target species; mesh size; number of sets. No interaction terms have been included. For simplicity, all terms are included in all models, except where inappropriate to the particular model.

Table 3 contains the definitions of the factors use for statistical area, month, and mesh size or number of sets and indicates which level is used in the base case in the analysis. Data could not be used where the statistical area was missing (or could not be inferred from the vessel's fishing pattern). Missing values of mesh size or number of sets that had not already been inferred from the data were placed in the most frequent grouping (Table 3).

All vessels that made 50 or more trips were included as individual level of the vessel factor in the model, the remainder were lumped into a single level. A vessel with the best record of presence in the fishery was chosen as the reference vessel in the standardisation. We follow Punt et al. (2000a) in using a categorical vessel effect and have not attempted to characterise the vessels by means of other variables (horsepower, tonnage, and so on) as has usually been done (for example, Vignaux 1994, 1996). This is because the efficiency of a vessel at catching school shark depends more on the skipper's targeting practices, skill level, and commitment to the fishery than on the attributes of the vessel. More powerful vessels may be able to set more net or longer lines and so may increase their catch, but need not change their catch rate.

It is necessary to specify the distribution of the errors in the dependent variables in the standardisation models before fitting to the data. Several error models were tested to determine the most appropriate one.

1. Lognormal — this error model has been used in most previous attempts at standardising catch and effort data (for example, Gavaris 1980, Kimura 1981, Vignaux 1994). However, in order to use it, it is necessary to make adjustment for zero catches. A constant 1 kg per km was added to the set net catch rates and 5 kg per 1000 hooks to the longline catch rates.
2. Poisson — one advantage of using this error-model is that it allows zero catches to be included in the analyses, so there is no need to add a constant to the data. The dependent variable in this case was catch to the nearest integer. A log link function was used. The logarithm of the effort variable was included as an offset (Bradford 1996, Nishida 1996).
3. Gamma — this error model also requires that a method be specified to take account of zero catches. A constant was added to the catch rates as above. A log link function was used.
4. Negative binomial — this error-model allows for a more general relationship between the residual variance and the expected catch. The dependent variable in this case was catch to the nearest integer. The logarithm of the effort variable was included as an offset.

5. Delta-X — this error model is based on the premise that it is possible to treat separately the question of whether a catch rate is zero or not, and the size of the catch rate given that it is non-zero (Vignaux 1994). For this investigation, the non-zero catch rates were modelled as lognormal or gamma while whether the catch rate is zero or non-zero was modelled as a Bernoulli random variable (that is, a binomial error-model was assumed when fitting the data). Fitting the binomial model to the data therefore involved specifying a model of the form:

   $$g(V) = \mu + \alpha_y + \cdots$$

   where g is the logit link function. Similar models were calculated for the catch greater than 10 kg as small catch rates appeared to be similar to zero catches. The estimation procedure may not be correct for delta-gamma models as the gamma distribution has a finite value at zero. Delta-Poisson and delta-negative binomial models were not attempted; these should be fitted iteratively (Lambert 1992, Perkins & Edwards 1996).

For models 1 to 4, the relative catch rate index for year y (in a regional fishery) is determined by setting month, vessel, and so on, to some reference value. There is no loss of generality introduced by setting these terms to zero and ignoring the constant term, in which case the relative catch rate index (relative to the 1989–90 fishing year in this case) is given by

$$I_y = e^{\hat{\alpha}}.$$

For delta-X models, the value for I_y is computed by multiplying the probability for a non-zero catch by the expected catch rate given that the catch is non-zero. This is achieved by the equation:

$$I_y = V_y e^{\hat{\alpha}},$$

where V_y is the probability of a non-zero catch during year y. It is computed using the equation (Vignaux 1994, Punt et al. 2000a)

$$V_y = (e^{\phi_1+\phi_y+\phi_v+\cdots}) / (1+e^{\phi_1+\phi_y+\phi_v+\cdots}),$$

where

ϕ_1	intercept of the binomial expression
ϕ_y	binomial factor for year
ϕ_v	binomial factor for vessel
...	other binomial factors.

The delta-X models allow the variance in non-zero and zero catch rates to be explained by different variables. A difficulty with the school shark catch rate data is deciding on the dividing point between the zero (or small) catch rates and the rest. Zero and 10 kg/1000 m or 10 kg/1000 hooks were used.

The base case models in the set net fishery used trips when either school shark or rig was the target species. Alternative models were run with the school shark target trips only. School shark is the only shark target in the longline fishery (rig are not normally caught by longline).

Considerable quantities of school shark are caught as bycatch in some fisheries. The school shark bycatch rate of the ling longline fishery on the Chatham Rise, which is one of the more important bycatch fisheries, was standardised.

2.4 Diagnostics and model parameters

The model diagnostics given are $R^2(\%)$ (percentage of the residual sum of squares explained) for log linear models and *DE(%)* (percentage of the model deviance explained) and the dispersion for models estimated as generalised linear models. The dispersion is estimated as the Pearson chi-squared statistic divided by the degrees of freedom and should be 1 for Poisson and binomial models.

For the negative binomial model, the variance, σ^2, is related to the mean, μ, by $\sigma^2 = \mu + \mu^2/\theta$. The parameter, θ, is estimated during the model fitting procedure. As θ becomes large, the model tends towards Poisson and as θ becomes small, the model tends towards geometric (Venables & Ripley 1994). The values of θ are given for the negative binomial models, and where the model appears to give an adequate fit, its standard error, *s.e.* (θ), is given.

Standardised year indices are plotted (with standard errors) and residual quantile-quantile plots are plotted alongside for the lognormal and generalised linear models (if the residuals could be calculated). The standardised year indices for the delta-X models are plotted together with the corresponding index from the model that included zeros. Standard errors are not calculated for the delta-X models; to do so would require some form of bootstrapping (Coburn et al. 1999).

Residuals versus fitted values plots are given for the lognormal models including and excluding zeros and for gamma models excluding zeros.

2.5 Combining catch rates from different regions and methods

Quinn & Deriso (1999) described ways of combining catch rates from different regions and methods. This process is not described as problems with the standardised catch rates from the regional fisheries meant that producing a single catch rate index was not attempted.

3. RESULTS

3.1 Set net fishery

The regional set net fisheries in Southland, east coast South Island, west coast South Island, Cook Strait, Egmont, west coast North Island, and the northeast North Island were considered. The Cook Strait region contains two statistical areas from SCH 2; little set netting for shark is done in the rest of SCH 2 (see Table 2).

The shark set net fishery is predominantly for school shark in the south and changes to a predominantly rig fishery in the north. One consequence is that the numbers of trips available for analysis when the rig-only vessels were removed reduce by 50% or more on the west and north east coasts of the North Island, that is, in QMA 1 & 9 or SCH 1 (see Table 2). Another consequence is that the mesh sizes used decrease from south to north (Figure 2). (Mesh size is partially confounded with target species.) The number of trips in the school shark target set net fishery on the west coast of the North Island is below the cut off of 1000 used to determine which regional fisheries should be included in the analysis. Several other school shark target set net regional fisheries have trip numbers close to 1000 (see Table 2). These cases are of marginal reliability.

The numbers of vessels that made more than 50 trips and were treated individually in the standardisations are given in Table 2. Another dummy vessel has the lumped information about the trips made by the rest of the vessels. Not surprisingly, the regional fisheries with the most vessels are the east coast of the South Island and Cook Strait, but many of these vessels are predominantly targeting rig rather than school shark. The number of vessels making more than 50 trips in a target school shark fisheries is three or four in the regional fisheries in the north of the North Island (SCH 1).

Zero and low values dominate the catch rate distributions, with both rig target boats included or excluded. Mean catch rates tend to decrease from south to north (Figures 3 and 4).

The standardised models have some common features for all regional fisheries (Table 4, Figures 5–11, 14–18):

- All year indices for a regional fishery have the same essential shape but differ in detail.
- Lognormal and delta-lognormal models appear to give the best fits using the quantile-quantile plots as a guide (delta-lognormal models can be suspect for the school shark target only case due to problems with the binomial model).
- The fitted versus residual plots are distorted for nearly all lognormal models. The exceptions are a few models from the target school shark case where the numbers of low or zero catch rates are small (Figures 14, 17).
- The fitted versus residual plots for lognormal models are more or less acceptable when the models are run with zeros removed (Figures 15, 18). However several quantile-quantile plots show unacceptable non-linearity for these models.
- Poisson models are hyper-dispersed in all cases and should be rejected.
- Gamma models that include zero catch rates always fail in the base case (have dispersion approaching machine infinity or other technical problems). They are usually reasonably satisfactory in the school shark target only case where there are few zeros.
- Gamma models with zeros removed may be more acceptable than lognormal models with zeros removed in some cases.
- Negative binomial models never converge satisfactorily in the base case. They converge satisfactorily in some cases in the school shark target only case.
- Binomial models are often unsatisfactory for the school shark target only.

Thus, few if any of the error models tried are entirely satisfactory. Many of the problems appear to arise from the high percentage of zero catch rates in the base case (18–75%) and it certainly appears to be necessary to use a model structure that treats the zero catch rates properly. We have generally chosen delta-X models that split the catch rates into zero and positive values as the best models. Models in which the catch rates were split into small values and the rest are presented; they give effectively the same year indices as the standard delta-X models.

The shapes of the catch rate distributions (Figures 3 and 4) suggest that the high dispersion and general failure of the Poisson, gamma, and negative binomial models probably arise as a result of the large numbers of zero and very low catch rates. The "model" is a fit to the error distribution rather than to the data itself, but the shape of the data distribution can be an indicator of likely problems with model fitting. Negative binomial models are thought to be a satisfactory replacement for over-dispersed Poisson models. However, in these data, the same features that lead to very large dispersion seen in the Poisson models are probably causing convergence and other problems with the gamma and negative binomial models.

The low number of zero catch rates in some regions in the school shark target fishery (see Table 2) lead to problems with the binomial models. In some fisheries, there were no zero catches reported in the school shark target fishery in some years. To some extent, this will be a consequence of what "target species" is entered on the CELR forms. Many fishers are fishing for a quota-mix rather than a single target and may enter the species with the largest catch as their target species, or use some other method of determining the target. A technical problem in fitting binomial models may have arisen because the numbers of zero school shark catches reported appears to have risen over the past 10 years and the proportion of zeros can be very low in the base year (1989–1990) in the school shark target only fisheries. It is not clear whether this is a change in reporting procedure or a change in the fishery.

3.1.1 Southland

Most models can be rejected as too ill-fitting. The best model appears to be the delta-gamma model for the base case (Figures 5a, 5b, and 14–16). However the binomial models are somewhat over-dispersed (Table 4). The models for the school shark target only case are similar and no better fitting (Figures 5c, 5d, 17, and 18). (Most of the trips had school shark as target in Southland.)

Hurst & Bagley (1997) reported that the distribution of school shark was patchy in 1993 and centred mainly to the west of Stewart Island (results from the *Tangaroa* (1993–96) surveys). In other years, the fish were more generally distributed. The size range of fish included immature and mature fish from about 80 to 160 cm. Biomass trends are difficult to interpret because of generally low sample sizes, but may have fallen between 1993 and 1994 and then remained roughly constant. This apparent drop in biomass occurred earlier than a similar drop in the catch rate index.

Hurst & Bagley (1997) reported the relative biomass index for school shark from the *Shinkai Maru* (1981–86) that dropped slightly from 1981 to 1982 and then rose to 1996 (the 1986 value was about twice that in 1981).

3.1.2 East coast South Island

The best model appears to be the delta-lognormal model with zeros for the base case (Figures 6a, 6b, and 14–16). The year index declines from 1989–90 to 1994–95 and then remains flat at about 50% of the 1989–90 value.

The indices for the school shark target only case are similar except for a sharp peak in 1991–92 (Figures 6c, 6d, 17, and 18). This peak may have resulted from a dominant vessel in the fishery that had an abnormal fishing or reporting pattern in that year. The treatment of individual vessels as factors in the regressions should mitigate against such effects, but few vessels have a continuous history of participation in the school shark set net fishery in this area.

Beentjes & Stevenson (2000) reported that, in this area, school shark were confined to the shelf with highest catch rates in about 100 m. Few fish were caught and they were generally small. The estimated biomass was apparently higher in 1993, but was otherwise flat.

3.1.3 West coast South Island

The best model appears to be the delta-lognormal model with zeros for the base case (Figures 7a, 7b, and 14–16). The year index is mainly flat to slightly rising.

For the school shark target only case, all indices have roughly the same shape, perhaps rising, with somewhat lower values in 1993–94 and 1994–95 (Figures 7c, 7d, 17, and 18). The negative binomial model produces an acceptable fit and is possibly the best fitting of these models.

The estimated biomasses of school shark from trawl surveys on the west coast of the South Island also suggest a slightly rising trend (Stevenson & Hanchet 2000a).

3.1.4 Cook Strait

The best model appears to be the delta-lognormal model with zeros for the base case (Figures 8a, 8b, and 14–16). The year index is mainly flat with a slight U-shape.

For the school shark target only case, the negative binomial model is possibly the best fitting of the models, with an essentially flat year index (Figures 8c, 8d, 17, and 18). Several of the poor or badly fitting models have a peak in 1994–95 that may not be real (it is unrealistically large in some cases).

3.1.5 Egmont

An acceptable model is difficult to choose, but the delta-lognormal model is selected for the base case (Figure 9a, 9b, and 14–16). The year index may rise in the second year and then declines slightly after 1993–94.

For the school shark target only case, the delta-gamma model appears to be the best fitting, the year index appears to be slightly rising (Figures 9c, 9d, 17, and 18).

3.1.6 West coast North Island

Several of the vessels operating in the shark set net fishery in this area are rig-only vessels.

The best model is probably the delta-lognormal model for the base case (Figures 10a, 10b, and 14–16). The year index apparently roughly doubles between 1989–90 and 1990–91 and then oscillates around the higher value.

None of the models for the school shark target only case appear to be well-fitting: perhaps the best is the delta-gamma model or the negative binomial model (Figures 10c, 10d, 17, and 18). The year index has unlikely year-to-year changes, unless there is migration, changes in local distribution, or changes in reporting. The school shark target set net fishery is small in this area and these results are probably unreliable.

3.1.7 Northeast North Island

Several of the vessels operating in the shark set net fishery in this area are rig-only vessels.

The best model is probably the delta-lognormal model for the base case (Figures 11a, 11b, and 14–16). The year index almost halves between 1989–90 and 1990–91, recovers in 1991–92, remains fairly flat until 1996–97, and then drops again.

For the school shark target only case the delta-lognormal models appear to fit reasonably (Figures 11c, 11d, 17, and 18)

3.2 Bottom longline

A target bottom longline fishery for school shark occurs around New Zealand but only Cook Strait has sufficient trips for analysis (see Table 2). Rig is not usually a target of the bottom longline fishery.

The catch rate distribution from Cook Strait is included in Figure 4 with the target set net catch rate distributions.

Model diagnostic results are included in Table 4. Residuals versus fitted value plots are included in Figures 17 and 18. The model fitting problems are generally the same as for the set net fishery.

3.2.1 Cook Strait

The delta-lognormal model is probably the best fitting of the models (Figures 12a, 12b, 17, and 18). All the year indices suggest a decline in the early years and then some recovery with fluctuations. The amount of recovery depends on the particular model, though the differences are unlikely to be statistically significant.

3.2.2 Bycatch of ling bottom longline fishery on the Chatham Rise

One of the important bottom longline bycatch fisheries for school shark targets ling on the Chatham Rise. This fishery, mainly using auto-longliners, has been developing since about 1991. Here, the data used are those trips on which school sharks were caught. The explanatory variables were converted to factors in a similar fashion to that used above. This is predominantly a winter fishery: the other fisheries discussed are predominantly summer fisheries.

Figure 13 contains the index using lognormal and gamma models (without zeros). The lognormal model appears to be the best fitting. The standardised year index rises to 1995–96 (with perhaps a drop in 1993–94) and then falls.

3.2 Trawl survey results from the east coast North Island

Stevenson & Hanchet (2000b), in their review of the trawl surveys on the east coast of the North Island said that school shark were caught throughout the survey area, mainly in depths greater than 50 m and north of Cape Kidnappers. The biomass indices are consistent and have moderate c.v.s (16–24%), but the low numbers of fish caught make it unlikely that the survey was monitoring abundance.

No standardised catch rate indices are available for this area.

4. DISCUSSION

4.1 Technical issues

The regression models are unsatisfactory unless the zeros and/or small values are treated properly.

It is possible that the transformation used is wrong. The lognormal models first take the logarithm of the catch rate (plus a constant if necessary) and then fit the model using a multiple regression function (the function ***lm*** in S©). This means that, in effect, the factor means are geometric means. The other models used the ***glm*** function. The way this function is implemented in S© leads to arithmetic factor means. Geometric and arithmetic means are likely to be sensitive to, and biased by, different types of outliers in the data. Some of the differences in year indices may be a result such biases occurring in one type of model and not the other.

The unsatisfactory results for Poisson and negative binomial models suggest that these models should be run in two parts with the small catch rates treated separately. Fitting such models strictly needs an iterative process because some zeros (small catch rates) belong to the Poisson or negative binomial model. Examples of such models are the zero inflated Poisson (ZIP model, Lambert (1992)) or the negative binomial with added zeros (NBAZ) as used by Perkins & Edwards (1996). Such models have not been implemented here as, although they are likely to produce a technically better fit to the data, they are unlikely to lead to a standardised index that has a trend substantially different from those shown. Punt et al. (2000a) appear to have used delta-Poisson and delta-negative binomial models without iteration, that is, used the same procedure as for a delta-lognormal model and this is strictly incorrect. The delta-gamma models produced in this report may also be incorrectly estimated.

4.1.1 Shape of catch rate distributions

The shapes of the catch rate distributions (see Figures 3 and 4) are similar to the catch and catch rate distributions observed in recreational fisheries. It has been shown with recreational fisheries data that detecting differences of 20% in mean catch rates from such distributions requires large sample sizes, and the confidence intervals about a mean catch rate are skewed and difficult to determine (Jones et al. 1995, Bradford & Francis 1999, Bradford 2000a, b). The same problems are likely to exist for the school shark data and similar simulation studies should be undertaken before any standardised catch rates are accepted.

4.1.2 Sensitivity to assumptions

Several assumptions have been made in the analysis, most importantly, the definitions of which vessels to include as individual factors and which trips to exclude. Ideally, the models should be re-run using other assumptions to test the sensitivity to such assumptions. This is not thought likely to improve the understanding of the standardised catch rates. The assumptions made could be tested within the simulation study suggested above.

4.1.3 Data problems

The CELR forms do not give suitable information (no positional or depth data are available) for good standardisation of catch rates in the set net and longline fisheries for school shark. The problems encountered arise through the inadequacies of the form design and the instructions for filling in the forms. Data entry errors also appear to occur. Recently, the Ministry of Fisheries have been working to minimise some of the problems.

It is difficult to know whether the raw catch rates used in the analysis are true values.

- The estimated catch weight often appears to be an estimated processed weight, not a greenweight.
- The net lengths given may not be the actual amount of net set during a trip. Replies from a questionnaire sent to shark fishers confirmed fears on this issue. No information is requested for the number of sets made. The catch rate from several shorter nets may be different from the catch rate of the same total net length set as one net.
- Similar problems are likely with the number of hooks set.

The data from the forms have been modified as far as possible to remove obvious errors. Catch weights were scaled by the ratio of annual landed weight to annual estimated weight totals for those vessels with larger school shark catches. Many net length and hook number values that appeared out of range were altered to fit the general pattern shown by a vessel.

4.2 Fishery effects

The need to hold quota for most species and the ubiquitous nature of school shark means that most fishers need to hold some quota to cover school shark bycatch. Hence many small parcels of school shark quota are held. Fishers may catch their quota in a very short time or over the whole year, say one shark per trip. Shark fishers with the larger parcels of quota are few and do not necessarily operate in a target shark fishery in all years. They can also catch their quota in a few trips. Some shark fishers seem to have left the fishery during the past 10 years.

Different mesh sizes are used in the set net fishery in different parts of New Zealand. This means that the net selectivities will be different and may or may not be matched to the population structure in the area. Catch rates could have somewhat different meanings from area to area. Mesh sizes from the industry log book scheme are plotted in Appendix A (Figure A1) and compared with the mesh sizes from the CELR data (see Figure 2). There is some disagreement in mesh sizes used on the east coast of the South Island, but there could have been a change in mesh size used over time.

The start of set depths from the industry log book scheme (Figure A2) confirm that the target school shark fishery lies basically within the 200 m depth contour, but replies to a questionnaire sent to some known shark fishers suggest that the shelf break might be a better boundary.

4.3 Variation in indices

The standardised catch rate indices vary around New Zealand (Figure 19). These indices may be really artefacts of data errors. Otherwise, they are manifestations of the fishers' ability (or luck) in finding school shark. In several instances above, it was suggested that the standardised catch rate indices changed too much from year to year to be indicative of abundance changes in a stationary fish population (given that the underlying raw catch rates are correct on average). The data series is too short to tell whether the observed fluctuations occur regularly, or whether any of the potential trends are persistent.

Raw catch rate indices were calculated using the ratio-of-means estimator and then "standardised" by the 1989–90 value (Figure 19). The ratio-of-means estimator of mean catch rate (mean catch divided by mean effort) is used in recreational fisheries when considering total extractions. If the errors in catch and effort are symmetrically distributed, this estimator of catch rate minimises their effect. However, the variance of the ratio-of-means estimator is difficult to construct analytically. All catch rate estimators, being ratio estimators, are prone to bias (Thompson 1992).

There are wide discrepancies between the standardised and raw catch rates for the west coast North Island and northeast North Island set net fisheries. The SCH 1 set net fishery is primarily a rig fishery and school shark catch rates are relatively small and possibly some peculiar catch rates in 1989–90 or 1990–91 are upsetting the standardisation.

Many of the standardised indices show anomalies around 1994–95. We have obtained most of the data collected by the industry run shark log book scheme. Some of those data, including length frequencies, are presented in Appendix A. Unfortunately, the Industry log books started just after these catch rate "anomalies" and thus do not help to determine what may have driven them.

4.4 Landings

The landings by Fishstock have generally risen slightly in the past 10 years (Figure 20), except in SCH 4 (Chatham Rise) where the landings peaked in 1995–96 and have since fallen. Landings are limited by the TACCs (that have risen very slightly over the 10 year period), but except in SCH 4 do not show a direct relation to the catch rate indices. Of course, such inconsistencies could result from changes in effort, but the proportion of the school shark landings from bycatch fisheries has grown from about 45% in 1989–90 to almost 60% in 1998–99 (Paul & Sanders 2001).

4.5 Earlier data

Unscaled ratio-of-means raw catch rate indices are also used in Appendix B where they are plotted with similarly calculated raw catch rate indices from the FSU data (Figure B1). There are some level discrepancies between the 1980s and 1990s indices, but they show the same short-term fluctuations.

4.6 Relation between catch rate and abundance

Dunn et al. (2000) investigated the calculation and interpretation of catch rate indices. They compared catch rate indices with independent biomass indices and with estimated biomass from stock reduction models and determined the type of relations that exist between catch rate and biomass.

The relation between school shark catch rate indices and abundance is likely to be hyperstable (Hilborn & Walters 1992, Dunn et al. 2000). The fishery is unlikely to sample the population randomly due to the sparse, patchy, and variable distribution of school shark, a small variable target fishery, and a widespread bycatch fishery. To make matters worse, the total school shark biomass is likely to be small (relative to that of the major commercial fish species).

It should not be assumed that the standardised catch rate indices calculated in this report (assuming they are correct indicators of catch rate) are directly proportional to abundance without further work.

4.7 Forming a national index

To combine the regional indices into a single New Zealand standardised catch rate index would require a belief that the standardised regional indices correctly represent the catch rate changes. The discussion above suggests that this belief is unlikely to be true, especially as there are doubts about the validity of the raw data.

Also, if a combined index were to be thought of as an abundance index, the regional catch rate indices would have to be proportional to abundance in the region and more information on school shark behaviour and movements than is available would be required. School sharks are aptly named and form schools of roughly the same size (swimming ability) and sex. Tagging experiments suggest that school shark move around New Zealand, with some travelling to Australia, during their lifetime (Hurst et al. 1998). This information has not been quantified into movement rates. Mature female school sharks move inshore to pup but do not necessarily spend much time in inshore waters. Hurst & Bagley (1997) commented on the patchy nature of school shark catches during the southern trawl surveys.

Thus we have not produced a single national catch rate index for school shark.

5. CONCLUSIONS

While there are no obvious overall signs of problems with the school shark stock, the stock should be managed conservatively until some method of estimating its abundance is found. All schooling species suffer the possibility of being fished almost to commercial extinction before there is a noticeable decline in catch rates. The Australians have only recently determined the decline in their school shark biomass with reasonable accuracy despite active research over many decades (Punt et al. 2000b).

The Inshore Working Group requested an assessment of the reliability/usefulness of the regional standardised catch rate indices and this is given below. None of the standardised indices are acceptable without reservation, though the indices in some fisheries appear a little better than in others.

Southland	The major school shark set net target fishery operates in Southland with some operators present in all years. Nearly all the standardisation models are too ill-fitting to be acceptable. The best models treat the zeros separately, but even these are of dubious value. The standardised indices should be used with extreme caution.
East coast South Island	There is a mixed shark set net fishery in this area. Again, the best standardisation models treat the zeros separately. The standardised indices should be used with caution.
West coast South Island	There is a mixed shark set net fishery in this area. Again, the best standardisation models treat the zeros separately. The standardised indices should be used with caution.
Cook Strait – set net	There is a mixed shark set net fishery in this area. Again, the best standardisation models treat the zeros separately, though the negative binomial model fits quite well for the school shark target case. The standardised indices should be used with caution.
Cook Strait – longline	This is a school shark target fishery and some boats have operated in all years. Again, the best standardisation models treat the zeros separately. Apparent differences between the standardised indices are unlikely to be real. The standardised indices should be used with caution, but the lack of trend may be real.
Egmont	There is a mixed shark set net fishery in the area. It is doubtful if any of the standardised indices are acceptable in the base case. The gamma model with zeros treated separately may be acceptable in the school shark target fishery. The standardised indices should be used with extreme caution.
West coast North Island	The set net fishery in this area is predominantly for rig. The best models treat the zeros separately. The standardised indices should be used with extreme caution, if at all.
Northeast North Island	The set net fishery in this area is predominantly for rig. The best models treat the zeros separately. The standardised indices should be used with extreme caution, if at all.

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Table 1: Definition of school shark fishing regions

Region	Code	QMA	Statistical area
Northeast North Island	NENI	1	1–10, 105–107
East coast North Island	ECNI	2	11–14, 201–204
Cook Strait	CKST	2/7/8	15–19, 37–39
East coast South Island	ECSI	3	20–24, 26, 301, 302, 303
Southland	SLND	5	25, 27–32, 501–504, 602
West coast South Island	WCSI	7	33–36, 701–706
Egmont	EGMT	8	40, 41, 801
West coast North Island	WCNI	9	42, 43, 45–48, 101–104
Kaipara Harbour[1]	KAIP	(9)	44
Chatham Rise	CHAR	4	401–412, 205, 206
Chatham Island	CHAI	4	49–51
Other	XXXX		

[1] Kaipara Harbour is included with the rest of the west coast North Island region for the set net fishery.

Table 2: Data set sizes in the school shark/rig target set net fisheries and the school shark target bottom longline fisheries: N_1 total number of trips available; N_2 after removal of trips with absent or small effort values; N_3 after removal of outlying catch rates; N after removal of opportunistic or rig-only vessels (base case data set used); N_0 number of zero catch rates in base data set; N_T number of school shark target trips in base case data set; N_{T0} number of zeros in school shark target data. Values of N_1 are given for those regional fisheries that are not used in the analyses. V_B and V_T are the numbers of vessels treated individually in the base case and the school shark target fisheries

				Base case		School shark target only		Vessel numbers	
Region	N_1	N_2	N_3	N	N_0	N_T	N_{T0}	V_B	V_T
Set net									
Southland	3 666	3 586	3 569	3 457	607	2 918	411	14	12
East coast South Island	5 380	5 152	5 152	4 833	1 028	1 734	265	30	14
West coast South Island	2 092	2 067	2 066	2 005	488	930	33	11	6
Cook Strait	7 747	7 223	7 218	6 086	3 001	1 105	132	32	8
Egmont	6 058	5 797	5 796	5 024	2 005	1 379	110	24	9
West coast North Island[1]	9 487	8 860	8 858	3 465	1 735	522	60	15	3
Northeast North Island	11 570	11 094	11 090	5 436	4 055	893	287	24	4
East coast North Island	593								
Chatham Rise & Island	18								
Bottom long line									
Cook Strait	3 896	2 867				2 858	58		16
Southland	132								
East coast South Island	26								
West coast South Island	287								
Egmont	375								
West coast North Island	303								
Kaipara Harbour	366								
Northeast North Island	338								
East coast North Island	69								
Chatham Rise & Island	141								

[1] Includes Kaipara Harbour

Table 3: Definitions used to produce factors in the standardisations

Statistical areas

Region	Statistical areas	Combined areas	Base area
Set net			
Southland	25, 27, 28, 29, 30, 31, 32	(28, 29, 30), (31, 32)	25
East coast South Island	20, 21, 22, 23, 24, 26	(21, 20), (23, 22)	20
West coast South Island	33, 34, 35, 36		33
Cook Strait	15, 16, 17, 18, 19, 37, 38, 39	(15, 16, 17), (19, 18)	18
Egmont	40, 41		40
West coast North Island	42, 43, 44, 45, 46, 47, 48, 101, 103	(103, 45, 46, 48, 47), (101, 42)	42
Northeast North Island	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	(2, 1), (4, 5, 3), (6, 7), (9, 10, 8)	2
Bottom long line			
Cook Strait	15, 16, 17, 18, 19, 37, 38, 39	(15, 16), (19, 18), (37, 39)	17

Months (calendar)

Region	Months combined	Base month
Set net		
Southland	(4, 5, 6), (7, 8, 9)	1
East coast South Island	(6, 7, 8, 9)	1
West coast South Island	(6, 7), (8, 9)	1
Cook Strait	(6, 7, 8, 9)	1
Egmont	(6, 7, 8, 9)	1
West coast North Island	(4, 5), (6, 7)	1
Northeast North Island	(6, 7, 8)	1
Bottom long line		
Cook Strait	(7, 8)	1

Mesh, number of sets

Region		Missing
Set net	Mesh ranges (mm)	
Southland	<185; ≥ 185 (base)	Target SPO: 175, SCH: 250
East coast South Island	< 170; ≥ 170 & ≤ 180 (base); >180	175
West coast South Island	< 170; ≥ 170 & ≤ 180 (base); >180	175
Cook Strait	≤ 170; > 170 & < 185 (base); ≥ 185	175
Egmont	< 160 (base); ≥ 160	150
West coast North Island	< 128 (base); ≥ 128 & ≤ 140; > 140	120
Northeast North Island	< 160 (base); ≤ 160	150
Bottom long line	Sets	
Cook Strait	1 (base), 2, 3, 4, 5 (and greater)	1

Table 4: Model parameters. R^2/DE is R^2 for the lognormal models and the percentage of deviance explained for GLMs; a value of -1.0 indicates that the model did not fit well enough to make a meaningful estimate of dispersion (estimated as the Pearson chi-squared statistic divided by the degrees of freedom and should be 1 for Poisson, binomial, and negative binomial models). θ is the second parameter estimated in the negative binomial models; large values of θ indicate that the fitted model is nearly Poisson, small values of θ indicate that the fitted model is nearly geometric. The standard error of θ, *s.e.*(θ), is given for models that might be acceptable. The factors that appear to be non-significant are listed; – non-fitting model; blank, all factors significant

Model	R^2/DE(%)	Dispersion	θ	*s.e.*(θ)	Non significant
Southland, set net					
Lognormal, all	44.6				mesh
Lognormal, no zeros	33.1				mesh
Lognormal, no small	32.0				mesh
Gamma	-1.0	$>10^{30}$			mesh
Gamma, no zeros	28.0	1.023			mesh
Poisson	-1.0	1 433.978			–
Binomial, zeros	48.0	1.261			area, mesh
Binomial, small	45.9	1.623			area, mesh
Negative binomial	-1.0	2.044	0.8256		–
Target school shark					
Lognormal, all	41.5				mesh
Lognormal, no zeros	19.5				mesh
Lognormal, no small	19.6				month, area, mesh
Gamma	-1.0	$>10^{30}$			–
Gamma, no zeros	15.8	0.875			mesh
Poisson	-1.0	1 638.329			–
Binomial, zeros	66.6	3.460			area, mesh
Binomial, small	62.3	21.248			–
Negative binomial	-1.0	1.119	0.5870		–
East coast South Island, set net					
Lognormal, all	29.9				mesh
Lognormal, no zeros	28.0				
Lognormal, no small	23.7				
Gamma	-1.0	3.694			–
Gamma, no zeros	26.3	2.639			area
Poisson	-1.0	454.753			–
Binomial, zeros	19.3	1.170			
Binomial, small	20.4	1.092			
Negative binomial	-1.0	456.397	118376		–
Target school shark					
Lognormal, all	31.6				
Lognormal, no zeros	27.6				area, mesh
Lognormal, no small	27.6				mesh
Gamma	24.5	3.539			mesh
Gamma, no zeros	24.8	2.625			area, mesh
Poisson	-1.0	603.776			–
Binomial, zeros	20.4	1.183			
Binomial, small	21.4	1.122			area
Negative binomial	-1.0	604.859	136529		–

Table 4 — continued

Model	*DE*(%)	Dispersion	*θ*	*s.e.*(*θ*)	Not significant
West coast South Island, set net					
Lognormal, all	56.2				
Lognormal, no zeros	50.1				area
Lognormal, no small	47.3				area
Gamma	37.4	2.480			
Gamma, no zeros	45.2	1.317			area
Poisson	-1.0	556.445			–
Binomial, zeros	37.3	1.077			
Binomial, small	39.8	1.110			area
Negative binomial	-1.0	-1.000			–
Target school shark					
Lognormal, all	28.1				
Lognormal, no zeros	26.4				area
Lognormal, no small	26.2				area
Gamma	24.8	1.030			area
Gamma, no zeros	27.1	0.953			area
Poisson	-1.0	756.446			–
Binomial, zeros	39.3	6.016			–
Binomial, small	41.2	10.652			–
Negative binomial	23.0	1.734	1.6676	0.0767	area
Cook Strait, set net					
Lognormal, all	43.5				
Lognormal, no zeros	36.0				
Lognormal, no small	36.1				
Gamma	-1.0	$>10^{30}$			–
Gamma, no zeros	41.3	2.167			
Poisson	-1.0	676.996			–
Binomial, zeros	27.3	1.072			
Binomial, small	28.3	1.074			
Negative binomial	-1.0	1.659	0.1417		–
Target school shark					
Lognormal, all	27.5				mesh
Lognormal, no zeros	20.2				
Lognormal, no small	20.9				
Gamma	19.7	1.854			mesh
Gamma, no zeros	20.1	1.493			area
Poisson	-1.0	1 180.032			–
Binomial, zeros	24.4	1.228			area
Binomial, small	22.0	1.232			month, mesh
Negative binomial	17.8	2.374	1.2674	0.0610	area
Egmont, set net					
Lognormal, all	39.9				area
Lognormal, no zeros	27.7				area
Lognormal, no small	32.3				area, mesh
Gamma	-1.0	4.792			area
Gamma, no zeros	27.8	1.811			area, mesh
Poisson	-1.0	823.451			–
Binomial, zeros	27.2	0.967			area
Binomial, small	25.7	0.993			area
Negative binomial	-1.0	1.790	0.3053		–

Table 4 — continued

Model	*DE*(%)	Dispersion	θ	*s.e.*(θ)	Not significant
Egmont, set net					
Target school shark					
Lognormal, all	17.8				area
Lognormal, no zeros	20.2				area
Lognormal, no small	27.6				area
Gamma	15.5	1.297			
Gamma, no zeros	18.8	1.072			
Poisson	-1.0	916.104			–
Binomial, zeros	21.6	0.907			mesh
Binomial, small	15.7	0.986			area, mesh
Negative binomial	-1.0	2.374	1.2674		–
West coast North Island, set net					
Lognormal, all	40.5				
Lognormal, no zeros	37.5				mesh
Lognormal, no small	37.2				
Gamma	-1.0	5.384			–
Gamma, no zero	36.8	1.840			mesh
Poisson	-1.0	433.568			–
Binomial, zeros	24.7	0.990			
Binomial, small	25.7	0.992			
Negative binomial	-1.0	1.802	0.2772		–
Target school shark					
Lognormal, all	41.2				
Lognormal, no zeros	18.0				month, area, mesh
Lognormal, no small	18.1				month, area, mesh
Gamma	14.9	1.162			
Gamma, no zeros	17.5	0.720			month, area, mesh
Poisson	-1.0	450.122			–
Binomial, zeros	67.9	1.074			area
Binomial, small	64.8	1.013			area
Negative binomial	12.8	0.885	0.7464	0.0455	month, area
Northeast North Island, set net					
Lognormal, all	48.5				
Lognormal, no zeros	58.3				
Lognormal, no small	54.4				
Gamma	-1.0	$>10^{30}$			–
Gamma, no zeros	55.4	1.649			
Poisson	-1.0	781.669			–
Binomial, zeros	30.9	1.017			
Binomial, small	33.3	1.012			
Negative binomial	-1.0	2.677	0.0802		–
Target school shark					
Lognormal, all	48.2				
Lognormal, no zeros	40.0				
Lognormal, no small	34.7				
Gamma	37.2	2.723			
Gamma, no zeros	36.0	1.229			
Poisson	-1.0	334.703			–
Binomial, zeros	42.4	0.970			mesh
Binomial, small	40.6	1.029			
Negative binomial	32.0	2.246	0.6969	0.0455	

Table 4 — continued

Model	*DE*(%)	Dispersion	θ	s.e.(θ)	Not significant
Cook Strait, long line					
Lognormal, all	21.3				
Lognormal, no zeros	25.1				
Lognormal, no small	24.8				
Gamma	21.7	1.064			
Gamma, no zeros	24.0	1.023			
Poisson	-1.0	587.914			–
Binomial, zeros	25.3	0.919			
Binomial, small	21.6	0.780			
Negative binomial	-1.0	589.011	209673		–
Chatham Rise, ling longline bycatch					
Lognormal, no zeros	31.2				
Gamma, no zeros	37.9	2.197			

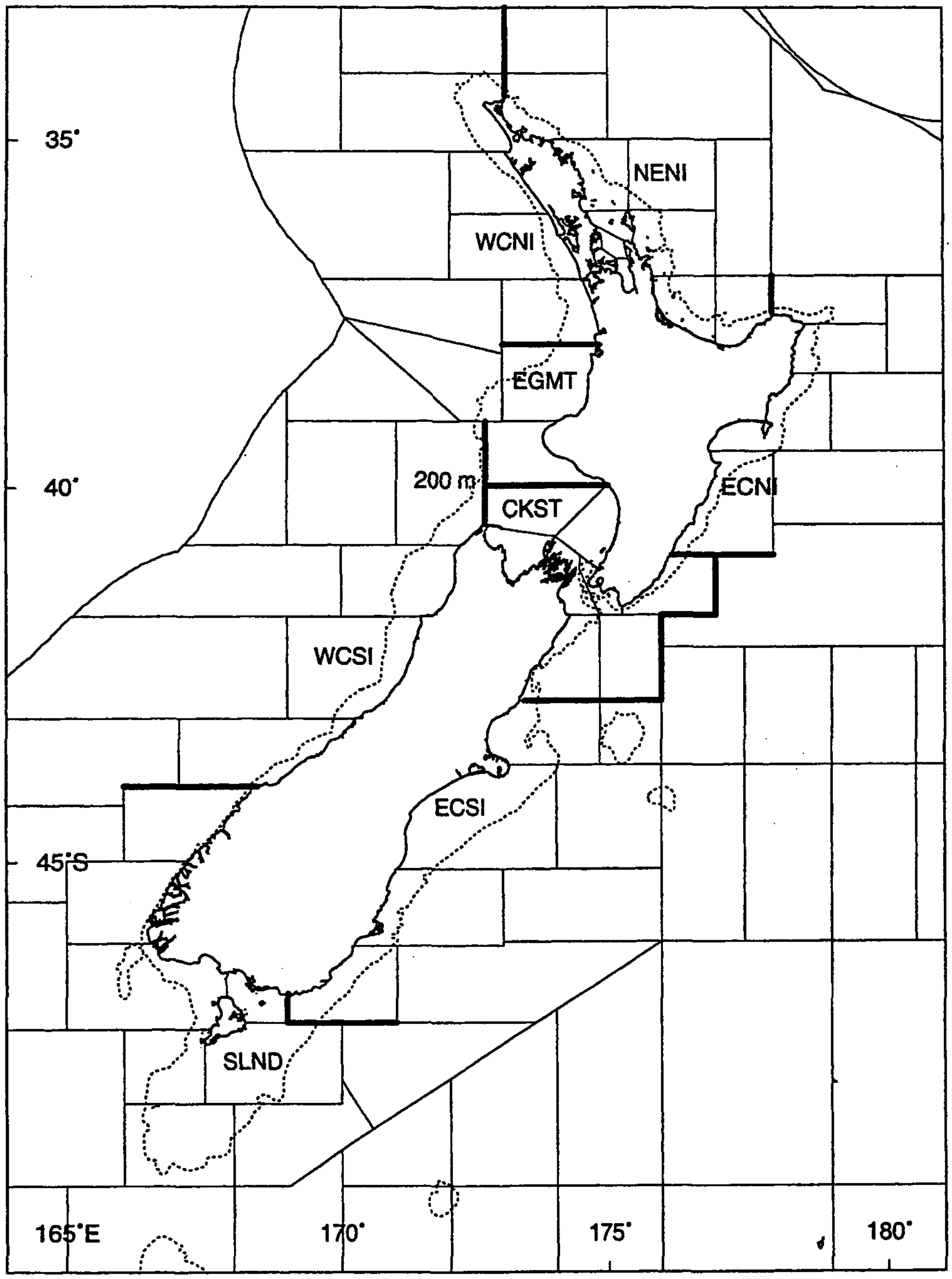

Figure 1: Map of New Zealand EEZ showing how the statistical areas are divided into the regions used in the analyses.

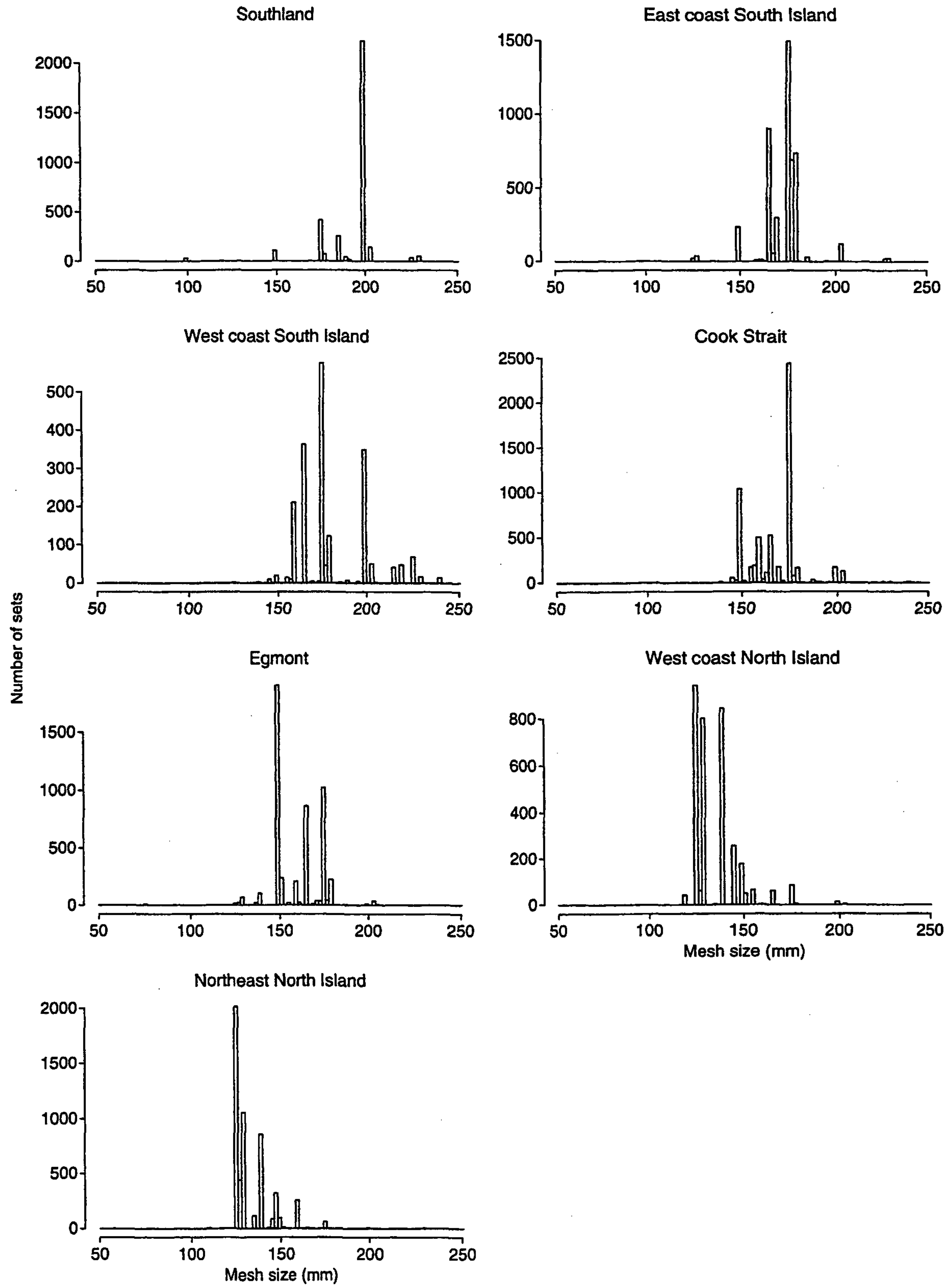

Figure 2: Mesh size distributions by region. The mesh sizes plotted are those that were available, lay between 50 and 250 mm, and were used in the analysis with both rig and school shark targets.

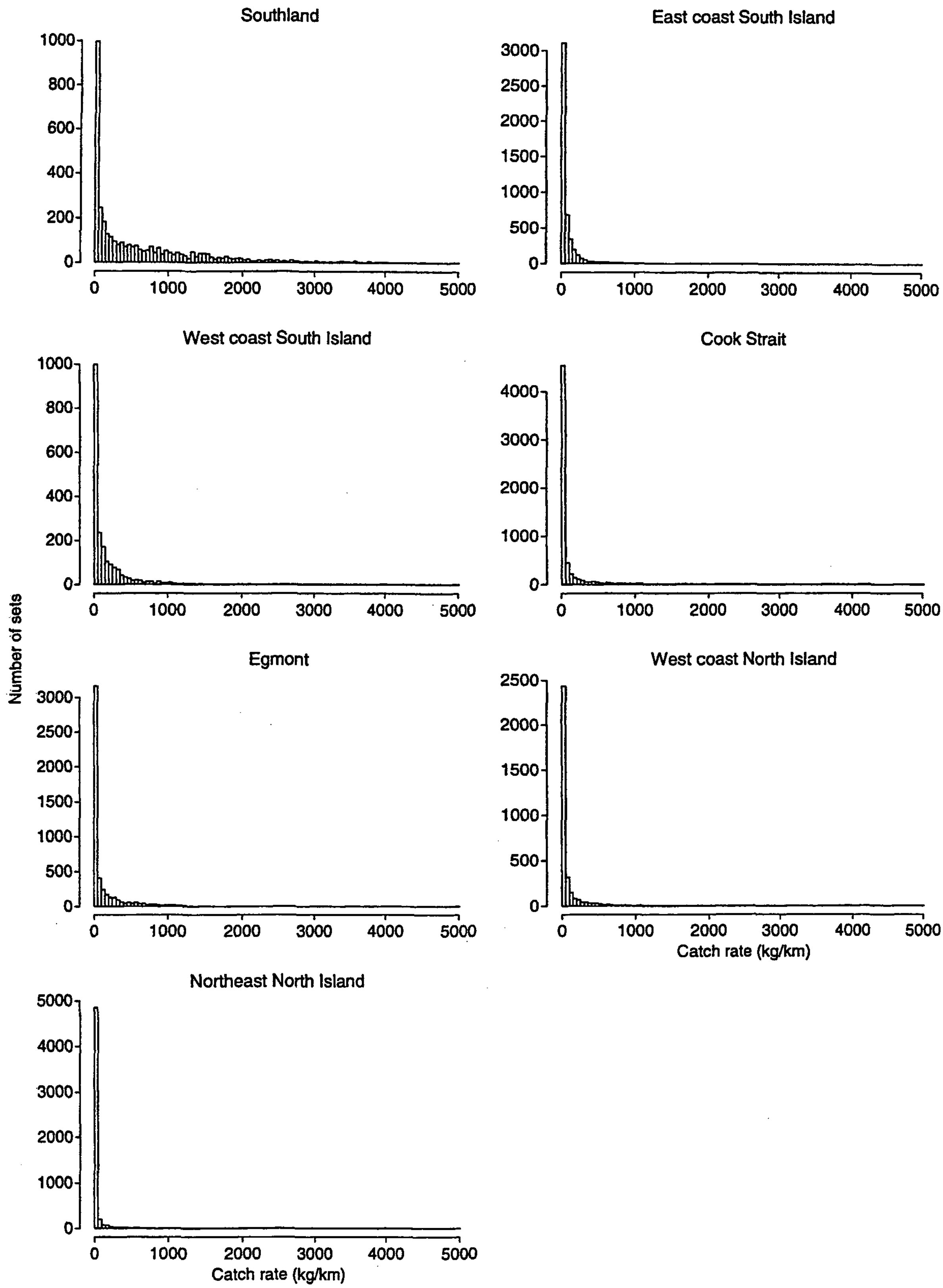

Figure 3: Catch rates included in the standardisation using both school shark and rig target sets for the set net fishery by region.

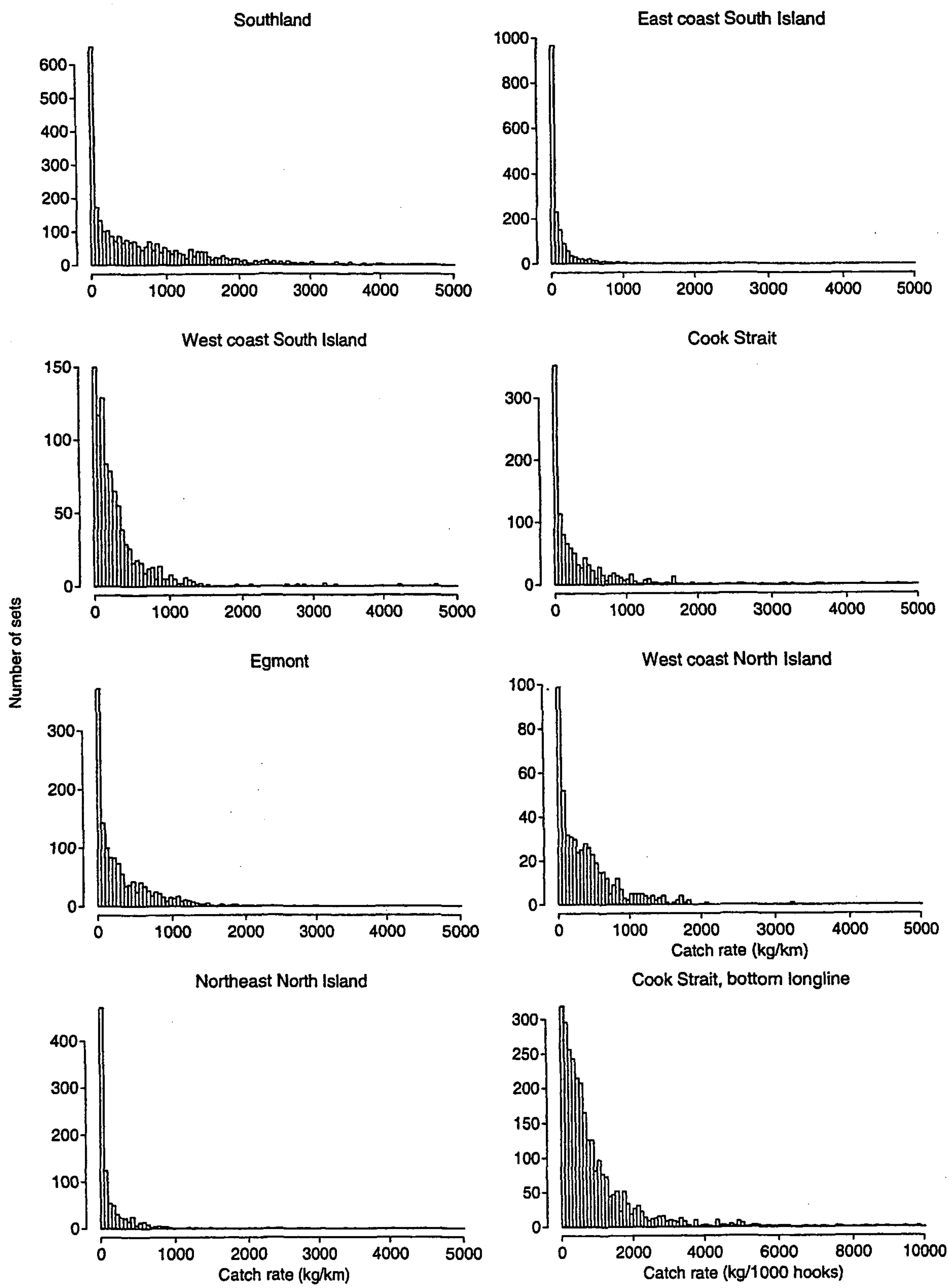

Figure 4: Catch rates included in the standardisation using school shark target sets for the set net fishery by region and school shark target sets in the Cook Strait bottom longline fishery.

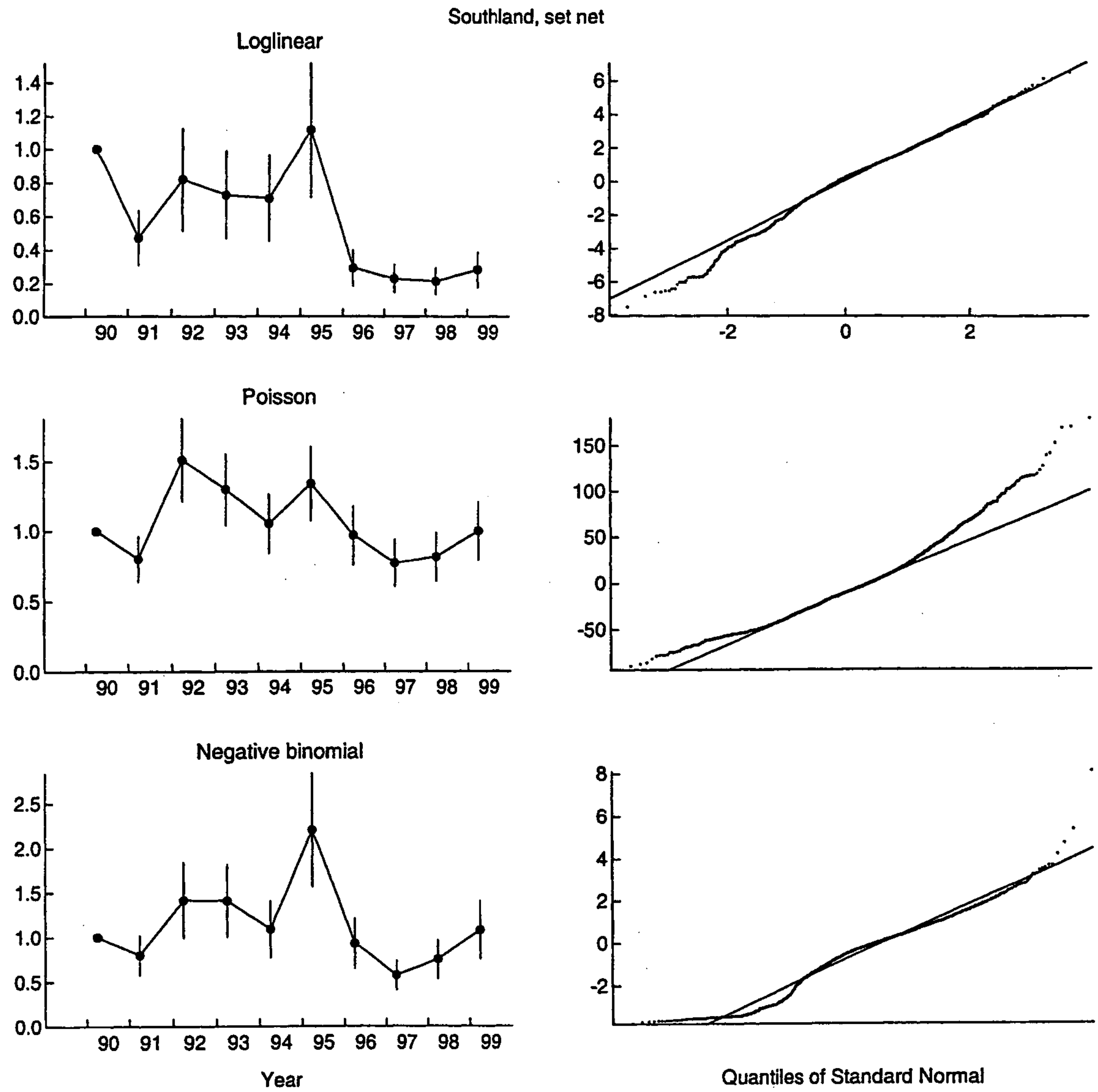

Figure 5a: Standardised catch rate indices and residual quantile-quantile plots for those models for which solutions were obtained. The data used were all sets from Southland.

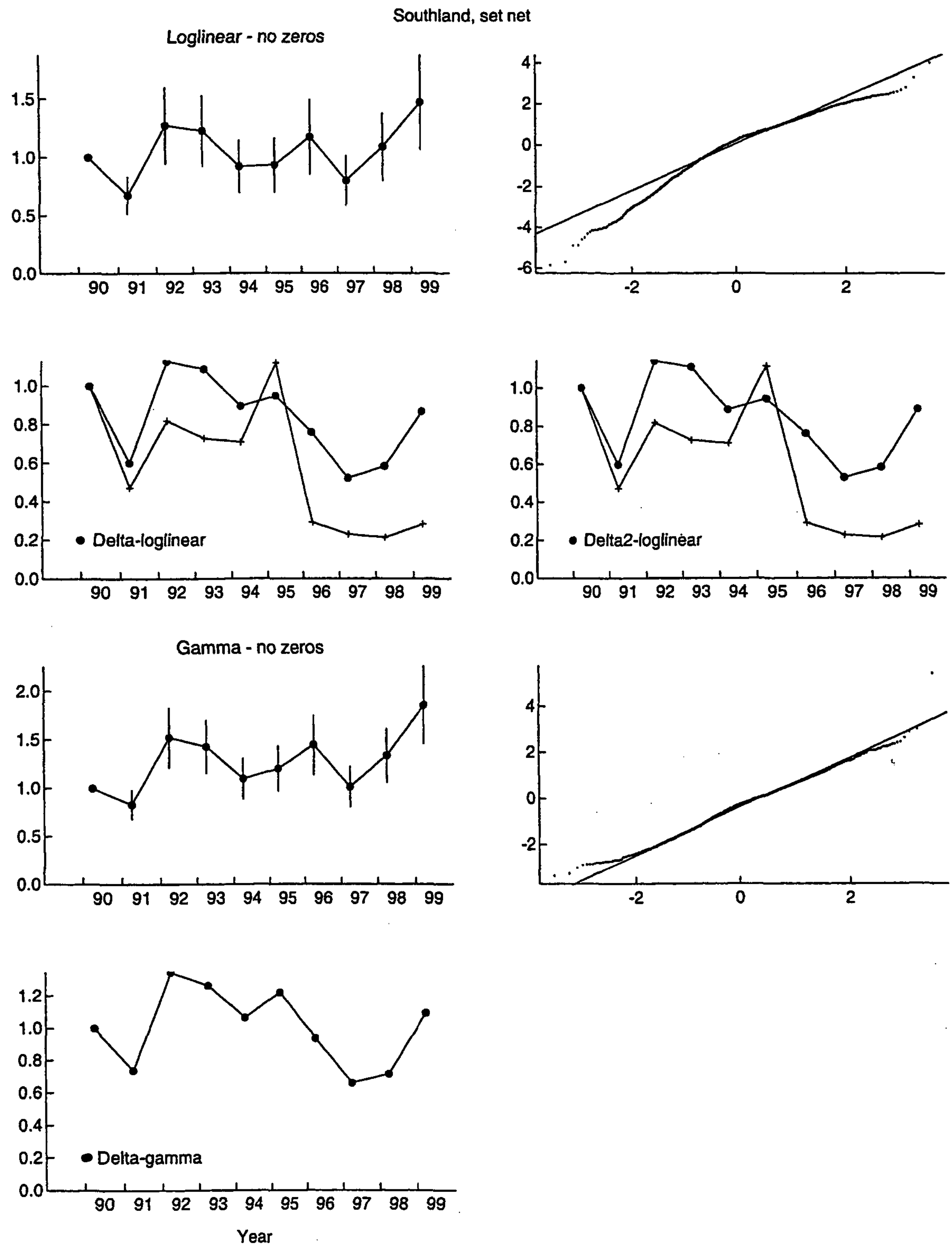

Figure 5b: Delta-X standardised catch rate indices. Where available, the comparison index is that for the model containing the zero catch rates. The data used were all sets from Southland.

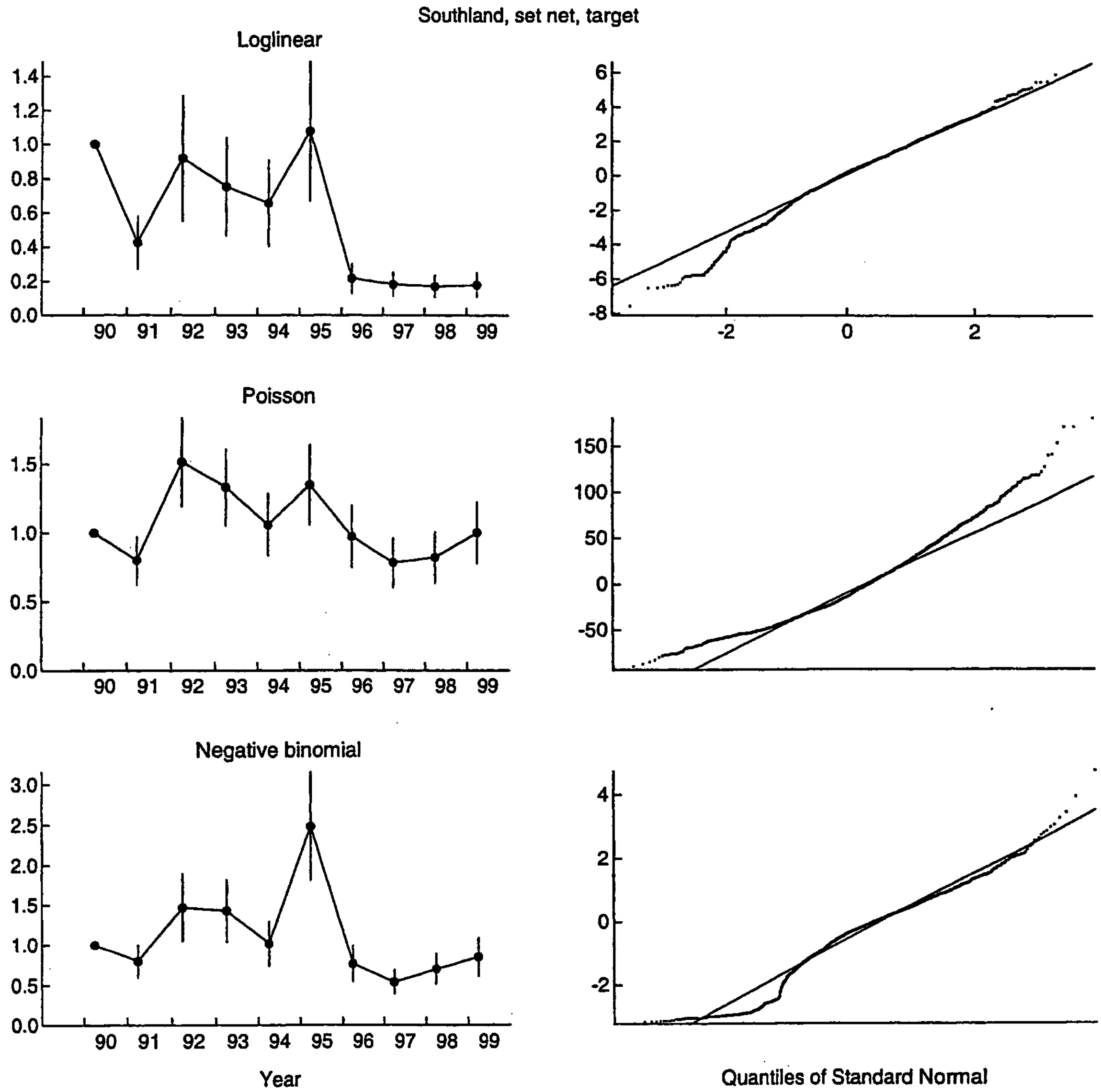

Figure 5c: Standardised catch rate indices and residual quantile-quantile plots for those models for which solutions were obtained. The data used were target school shark sets from Southland.

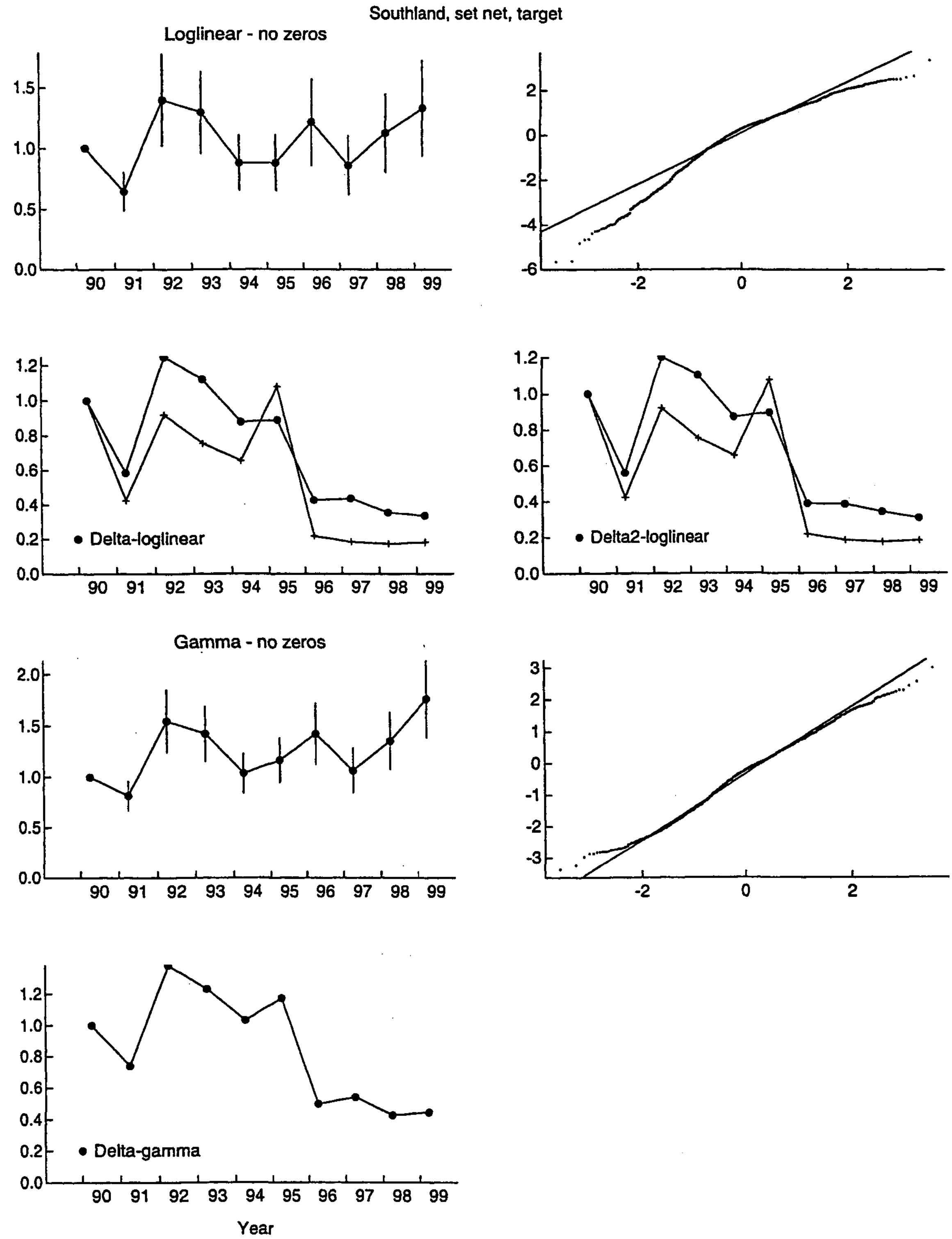

Figure 5d: Delta-X standardised catch rate indices. Where available, the comparison index is that for the model containing the zero catch rates. The data used were school shark target sets from Southland.

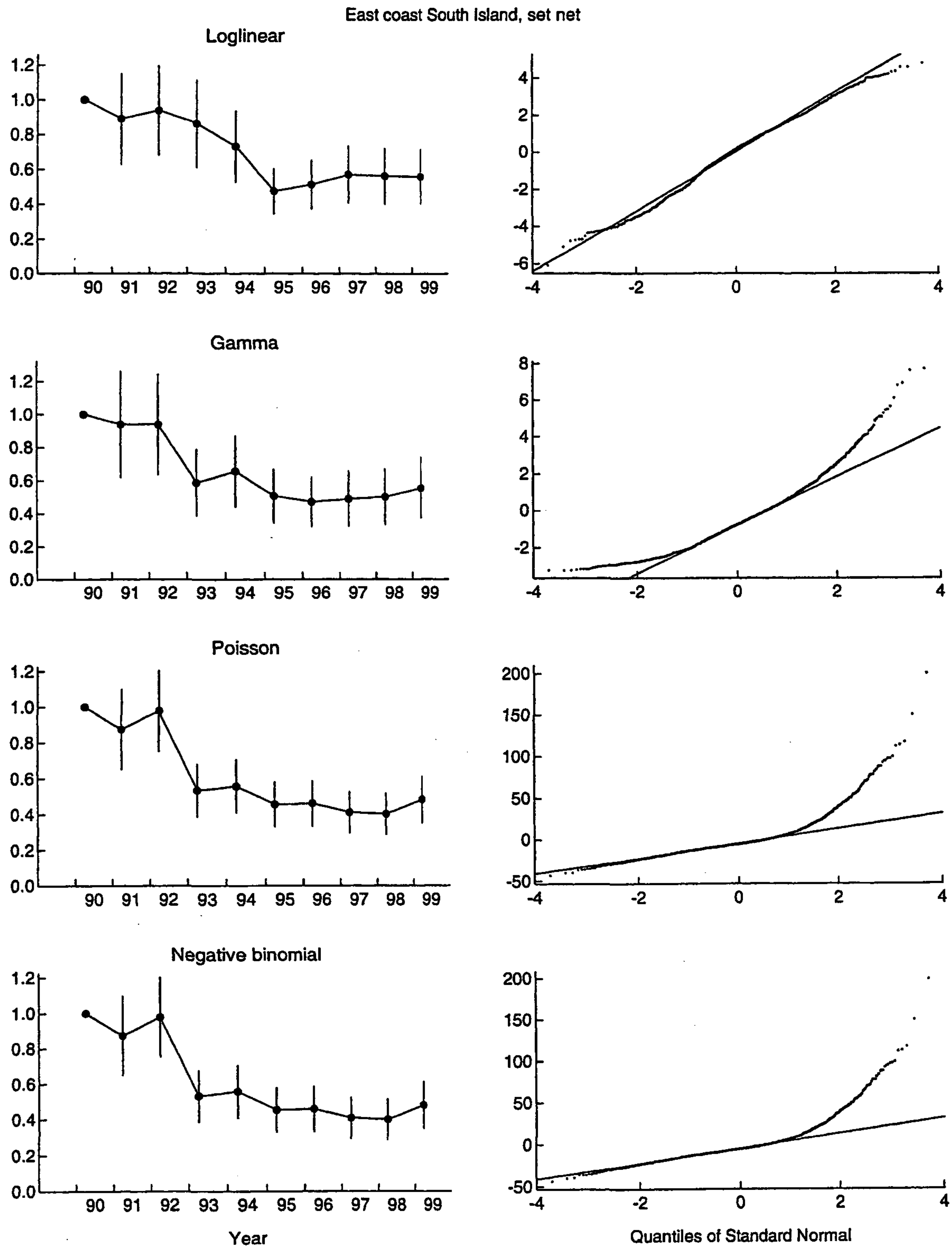

Figure 6a: As for Figure 5a but using data from the east coast South Island.

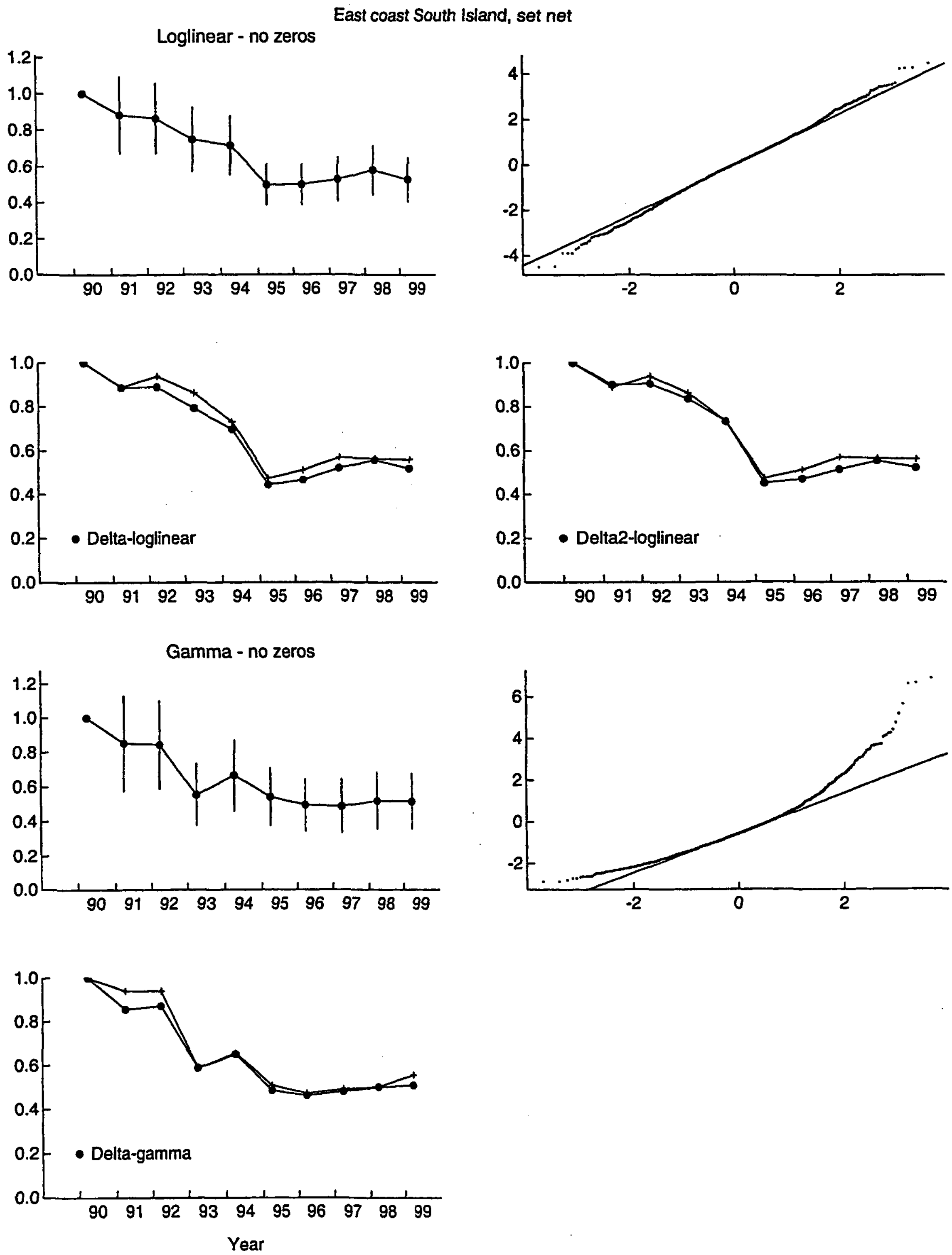

Figure 6b: As for Figure 5b but using data from the east coast South Island.

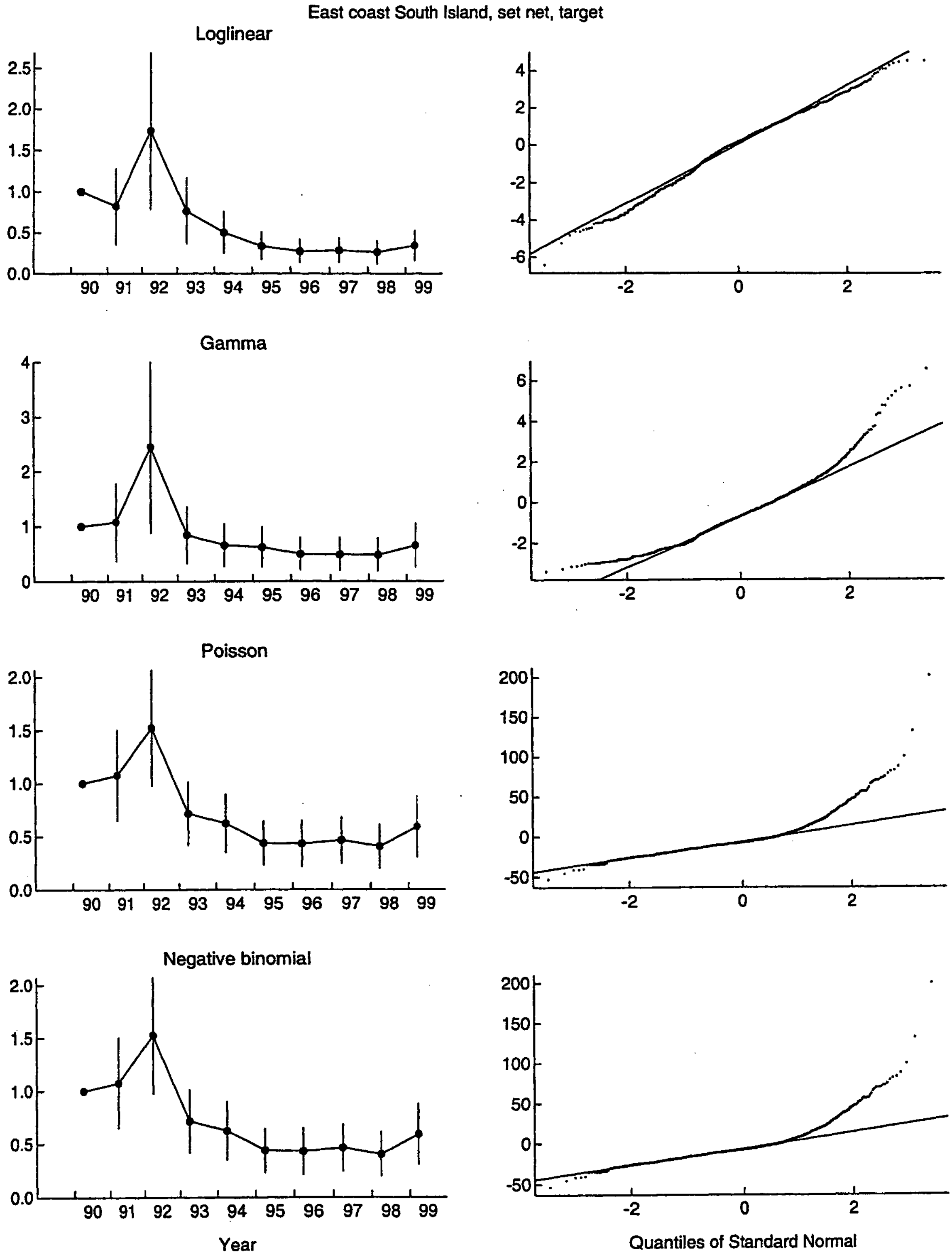

Figure 6c: As for Figure 5c but using data from the east coast South Island.

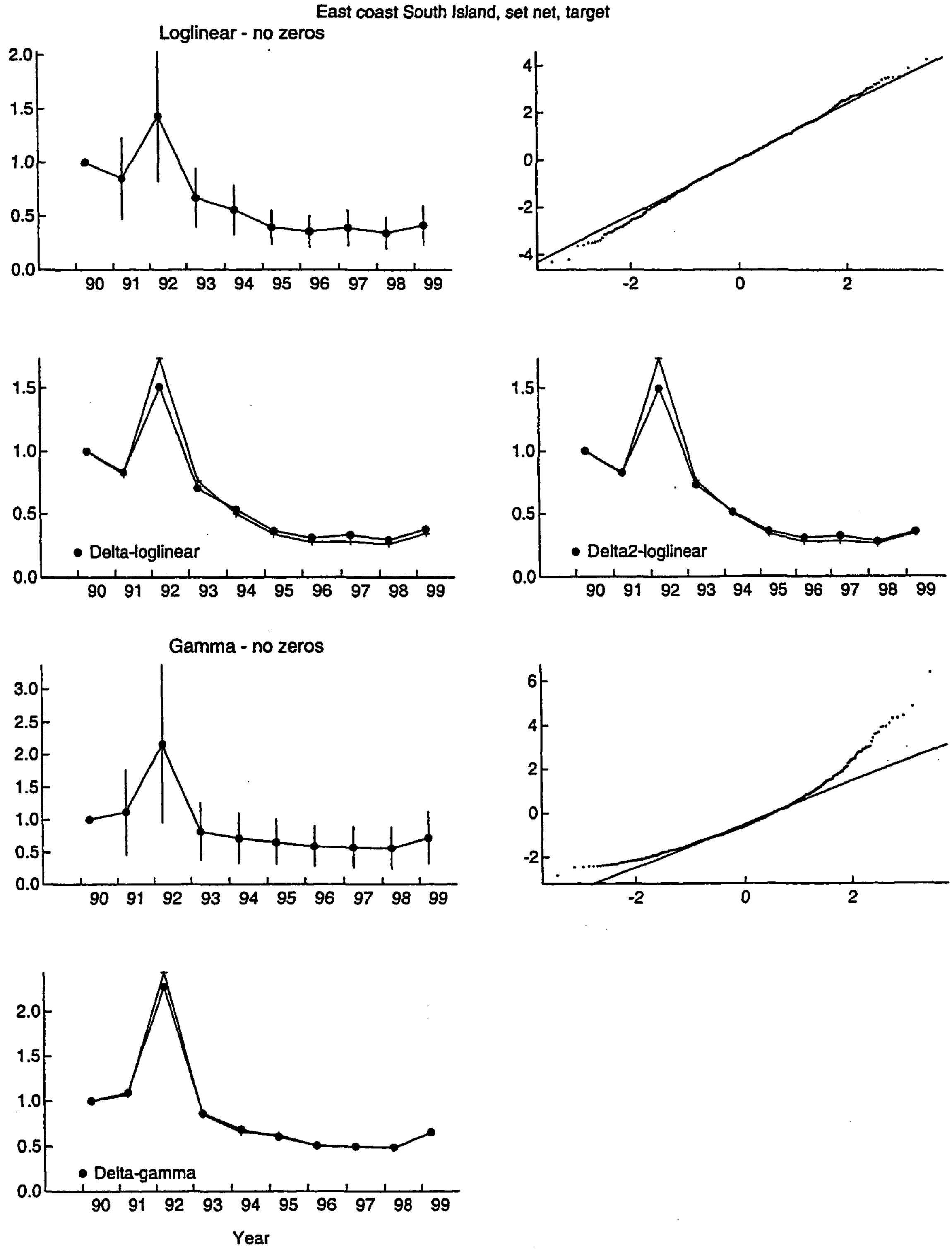

Figure 6d: As for Figure 5d but using data from the east coast South Island.

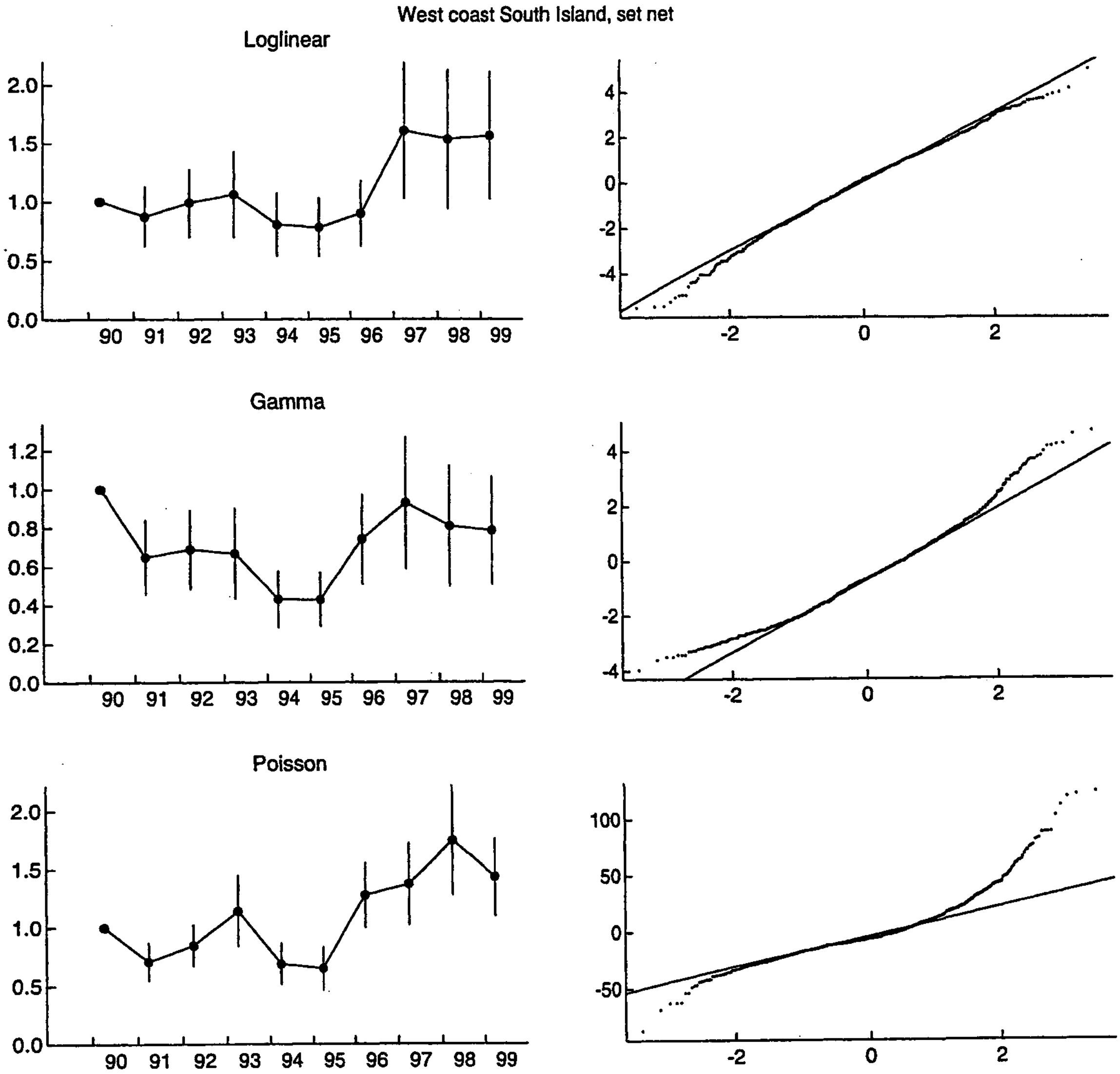

Figure 7a: As for Figure 5a but using data from the west coast South Island.

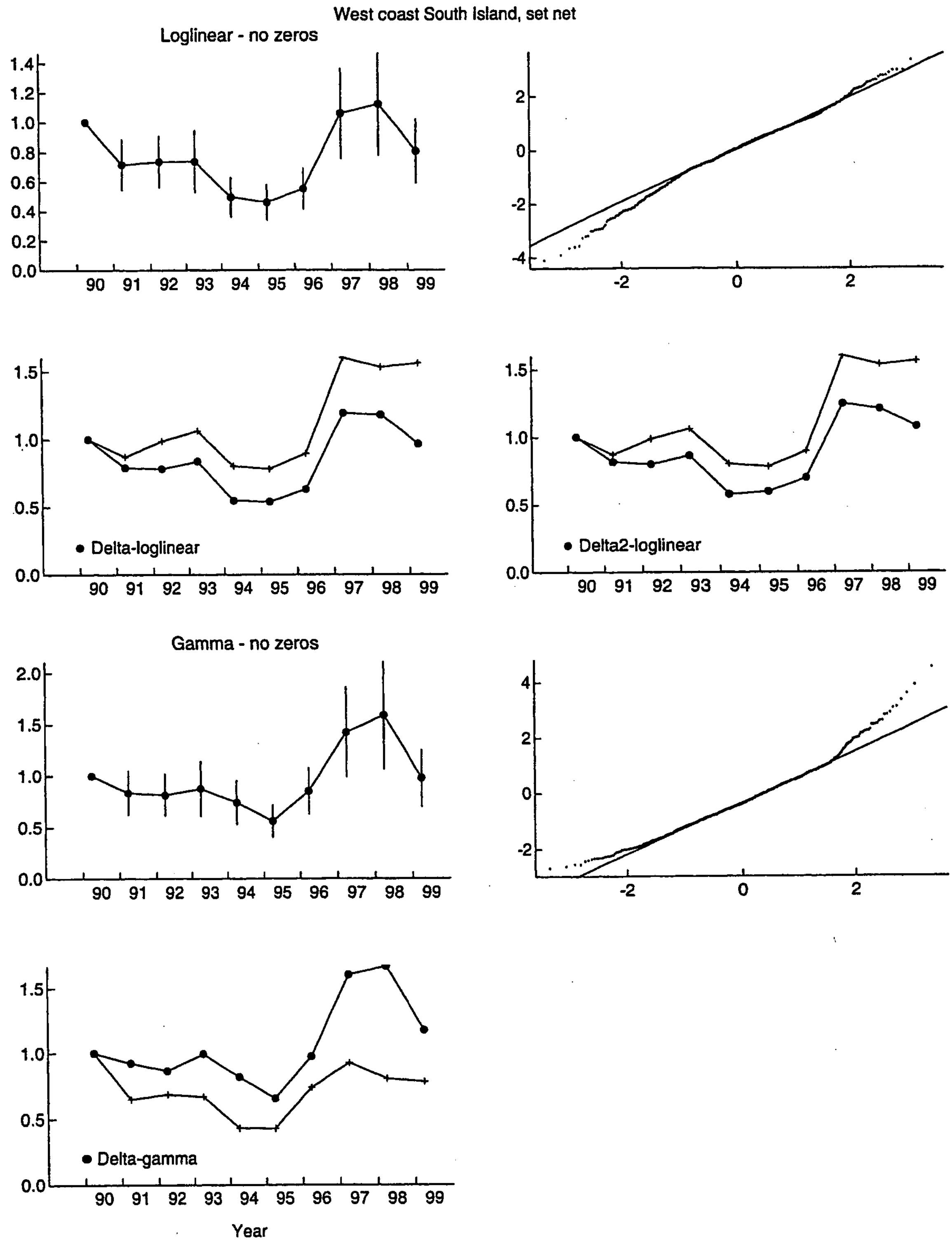

Figure 7b: As for Figure 5b but using data from the west coast South Island.

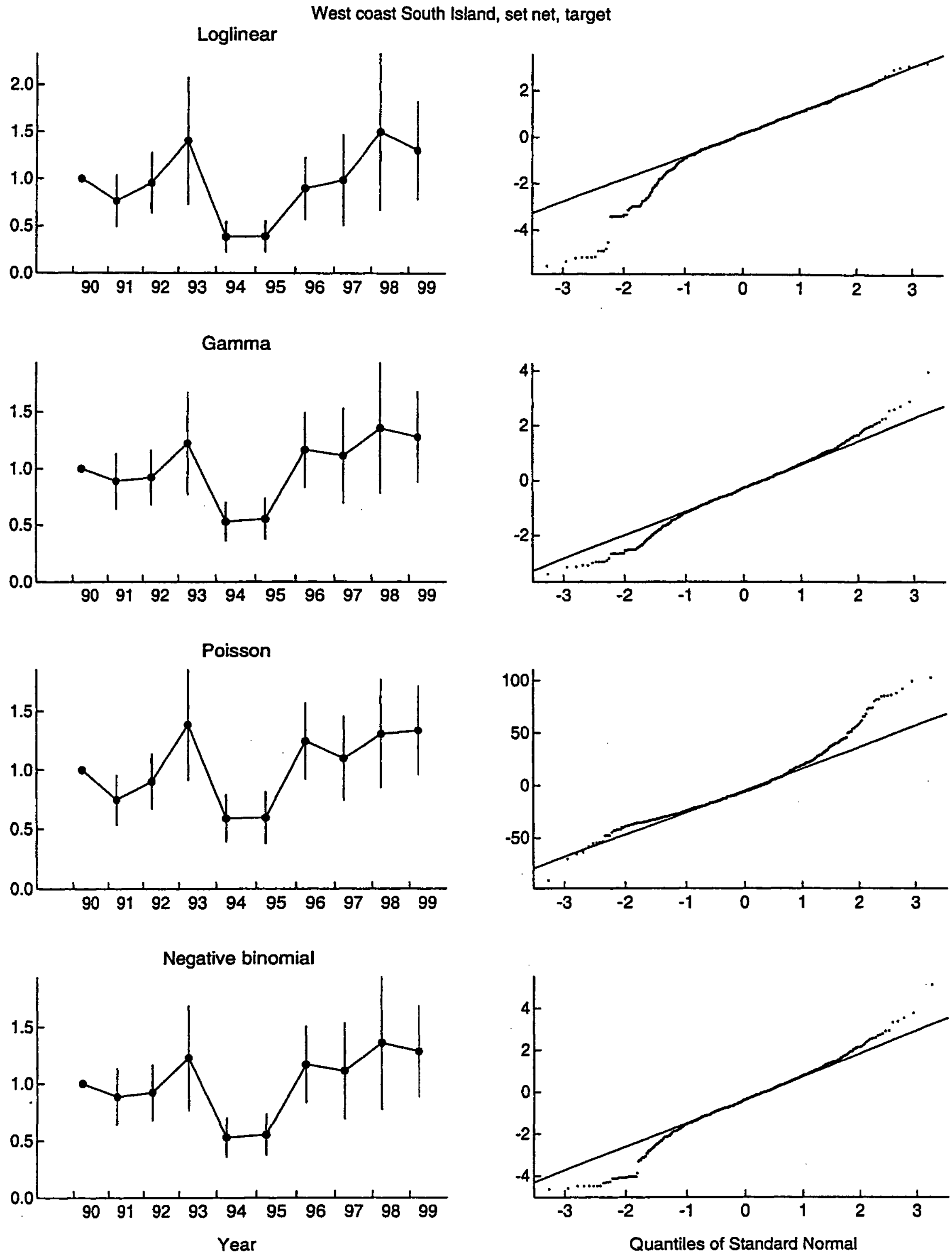

Figure 7c: As for Figure 5c but using data from the west coast South Island.

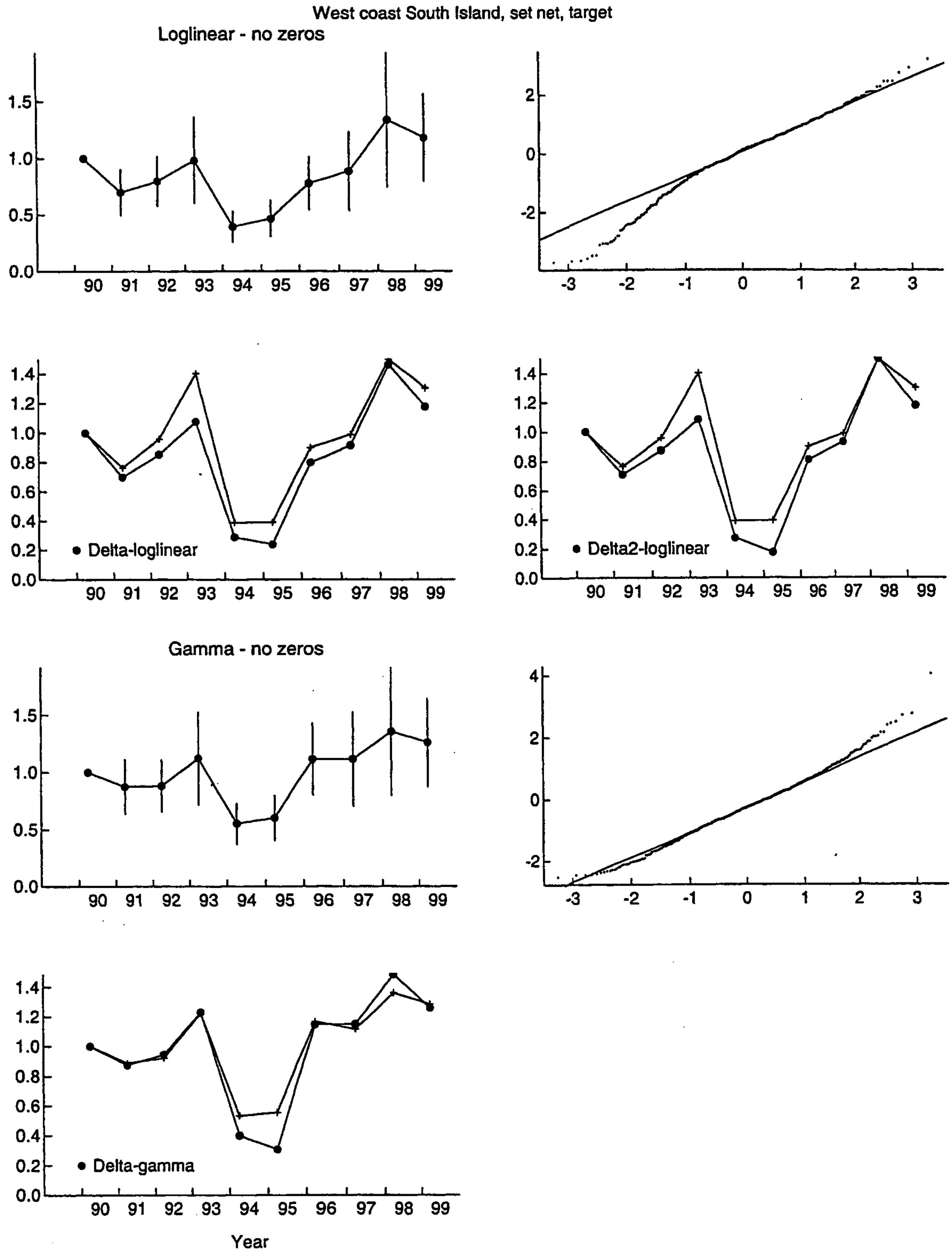

Figure 7d: As for Figure 5d but using data from the west coast South Island.

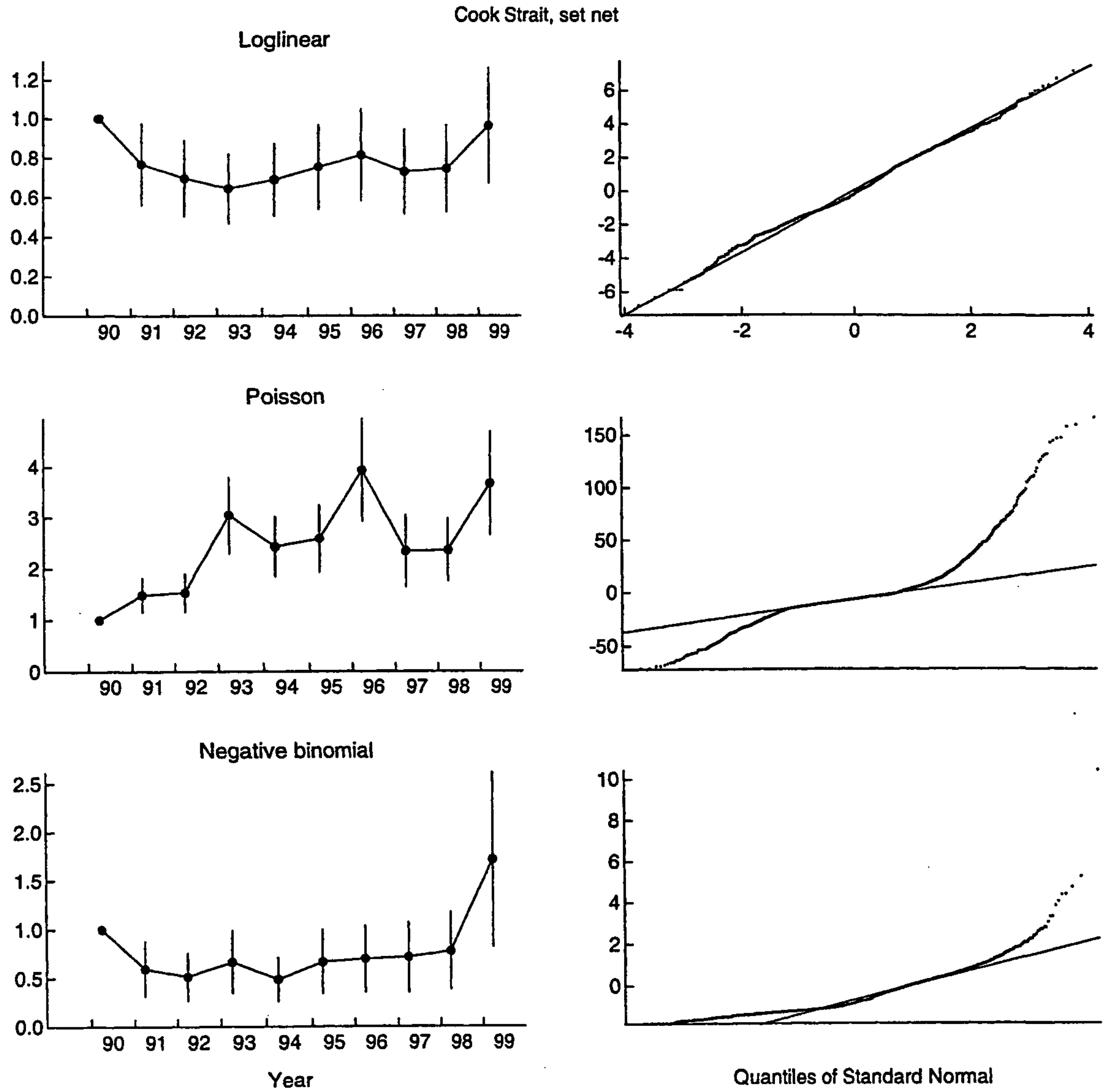

Figure 8a: As for Figure 5a but using data from Cook Strait.

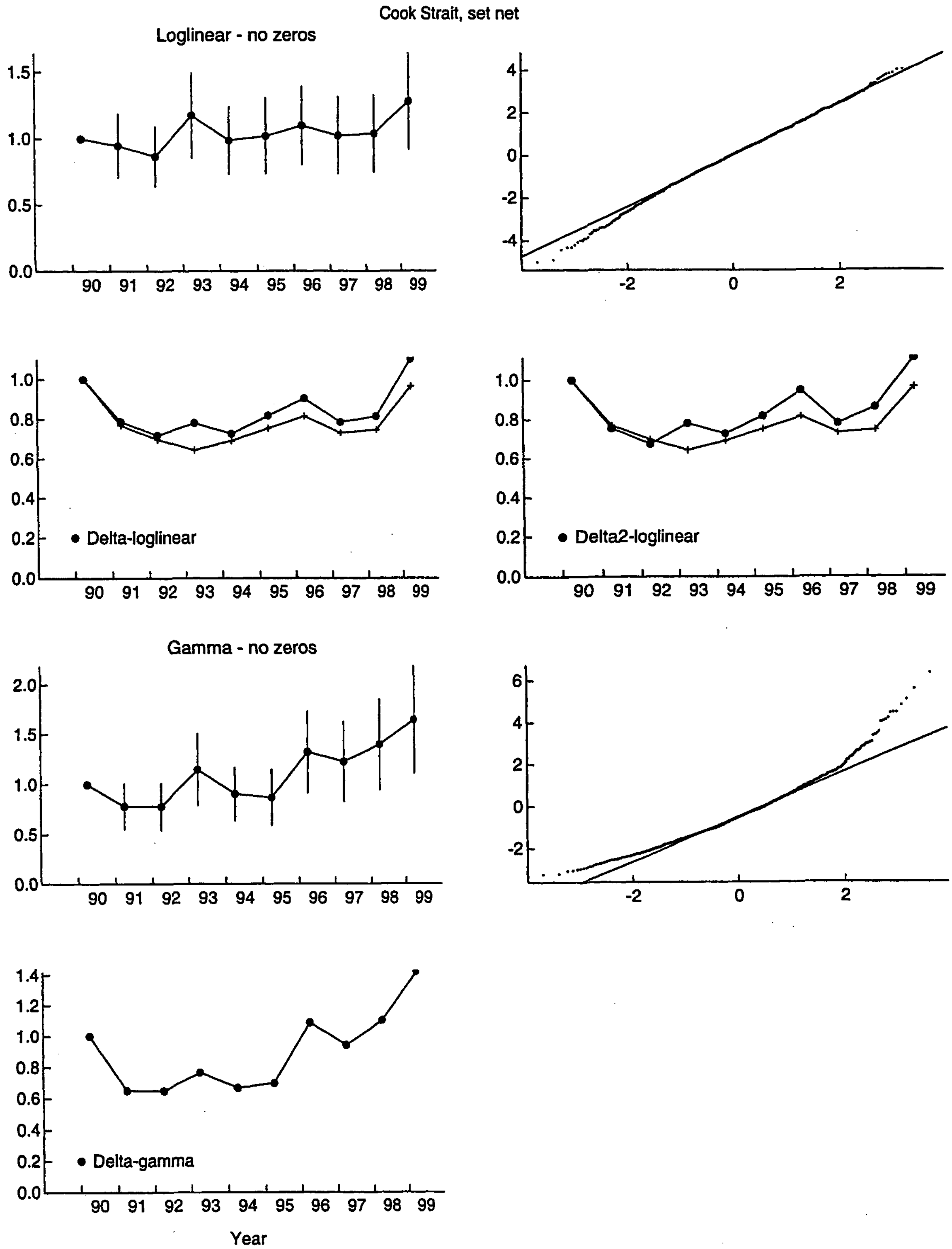

Figure 8b: As for Figure 5b but using data from Cook Strait.

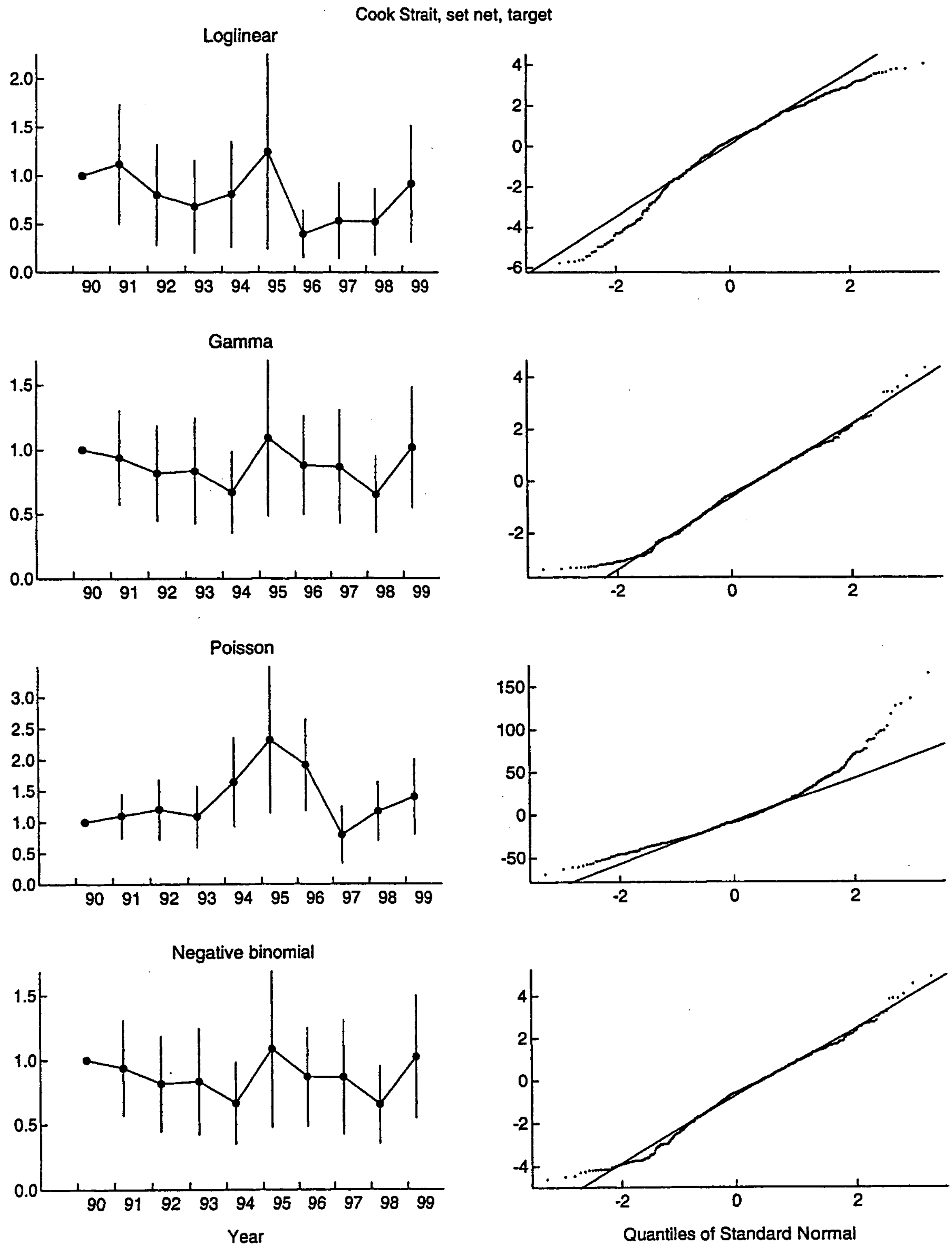

Figure 8c: As for Figure 5c but using data from Cook Strait.

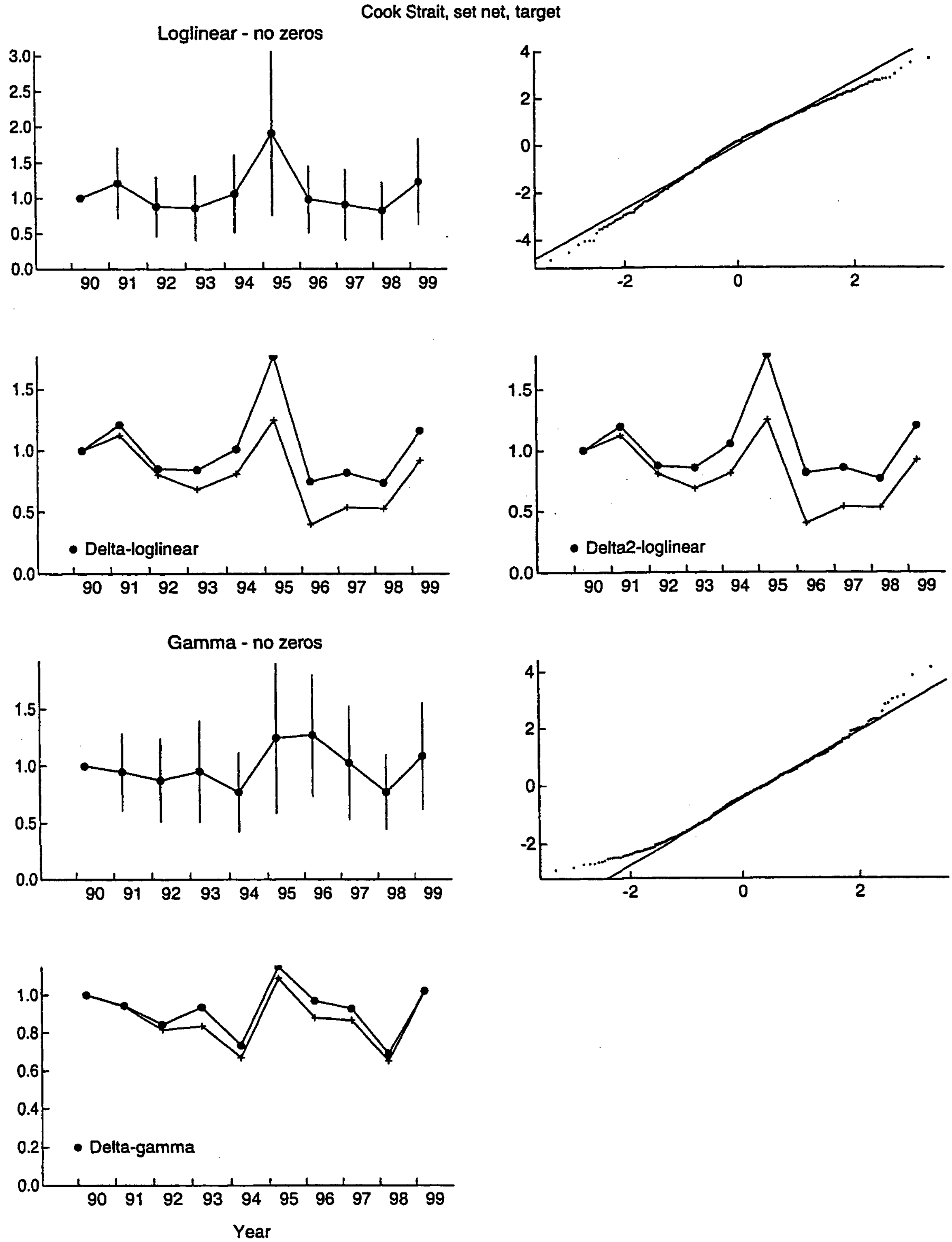

Figure 8d: As for Figure 5d but using data from Cook Strait.

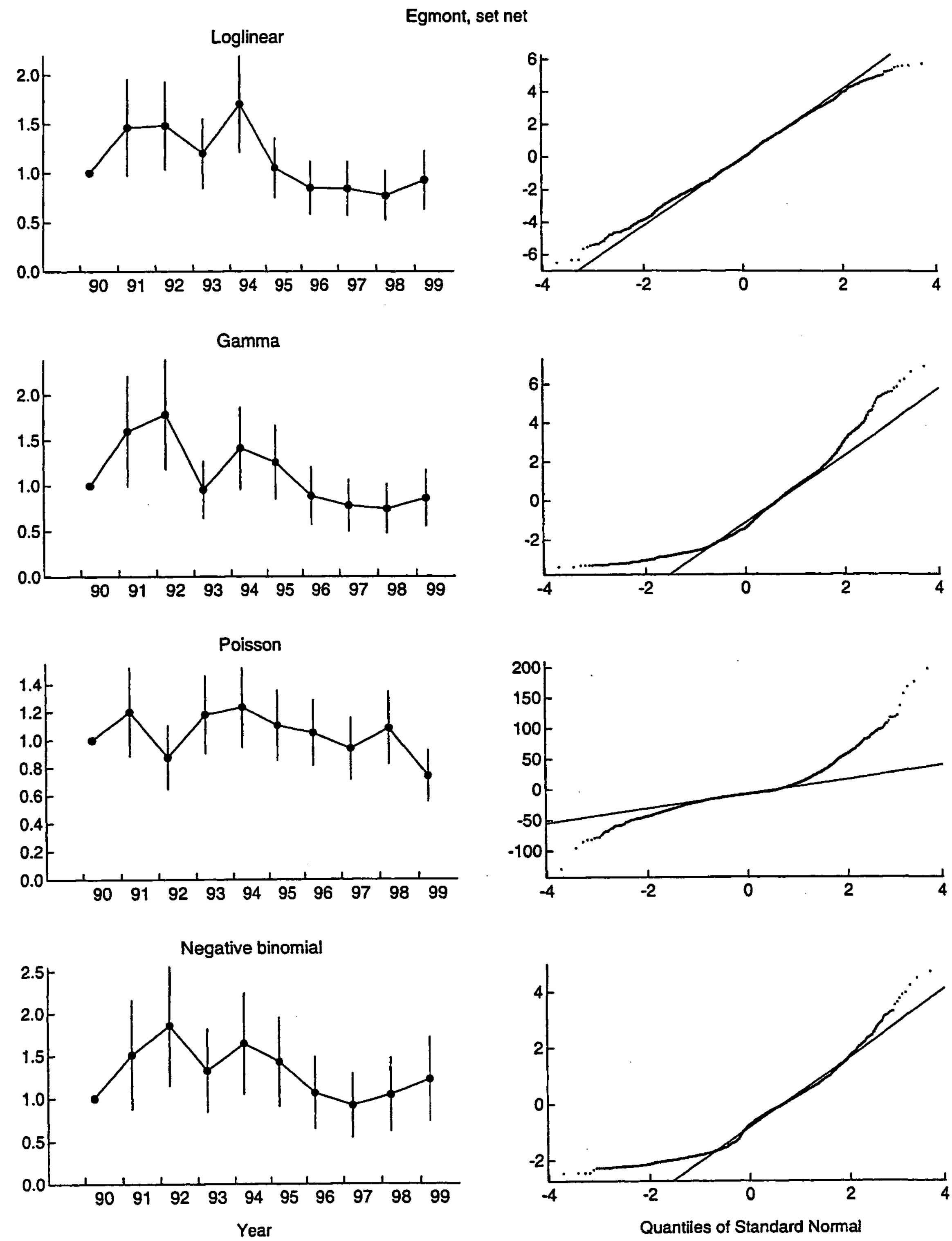

Figure 9a: As for Figure 5a but using data from Egmont.

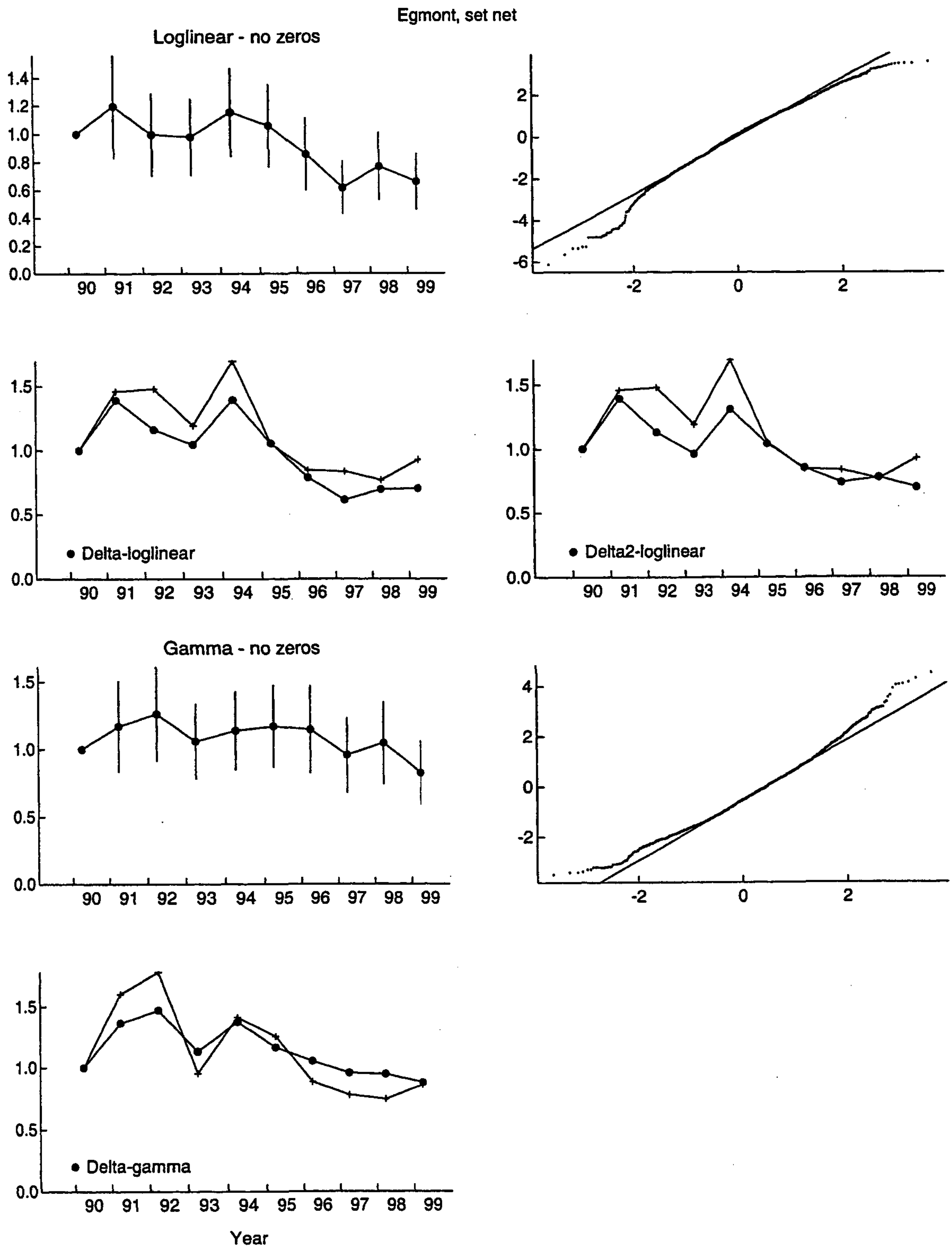

Figure 9b: As for Figure 5b but using data from Egmont.

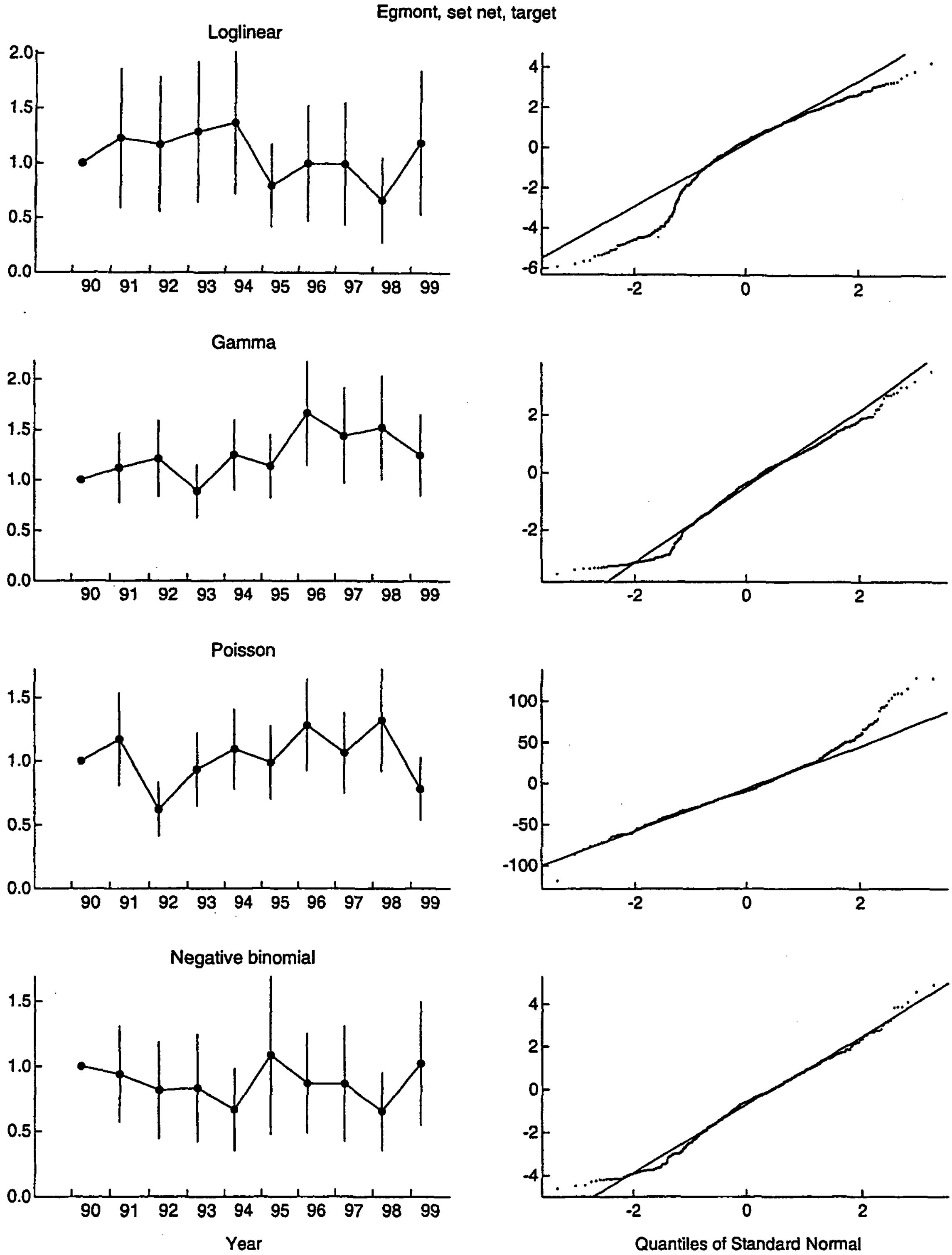

Figure 9c: As for Figure 5c but using data from Egmont.

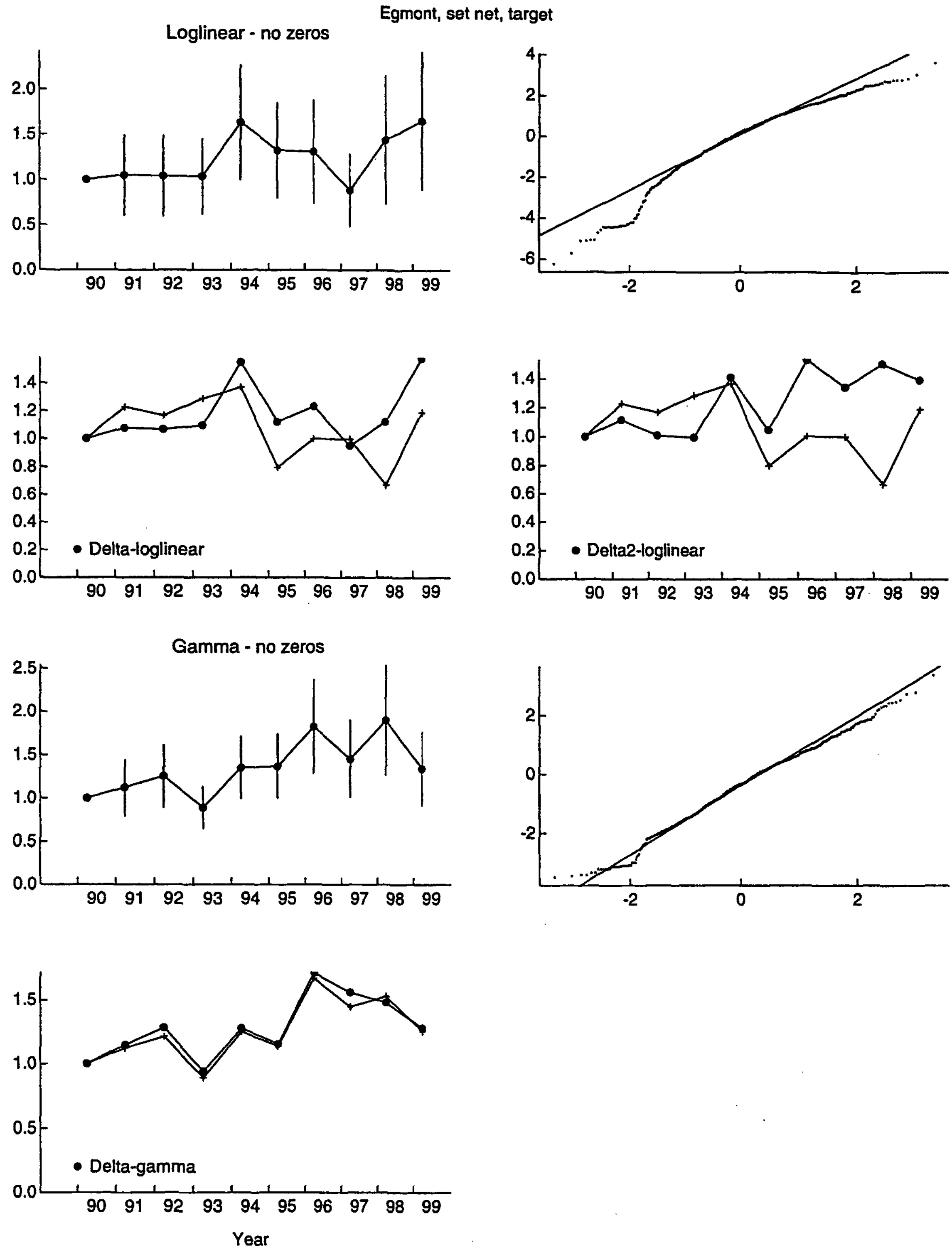

Figure 9d: As for Figure 5d but using data from Egmont.

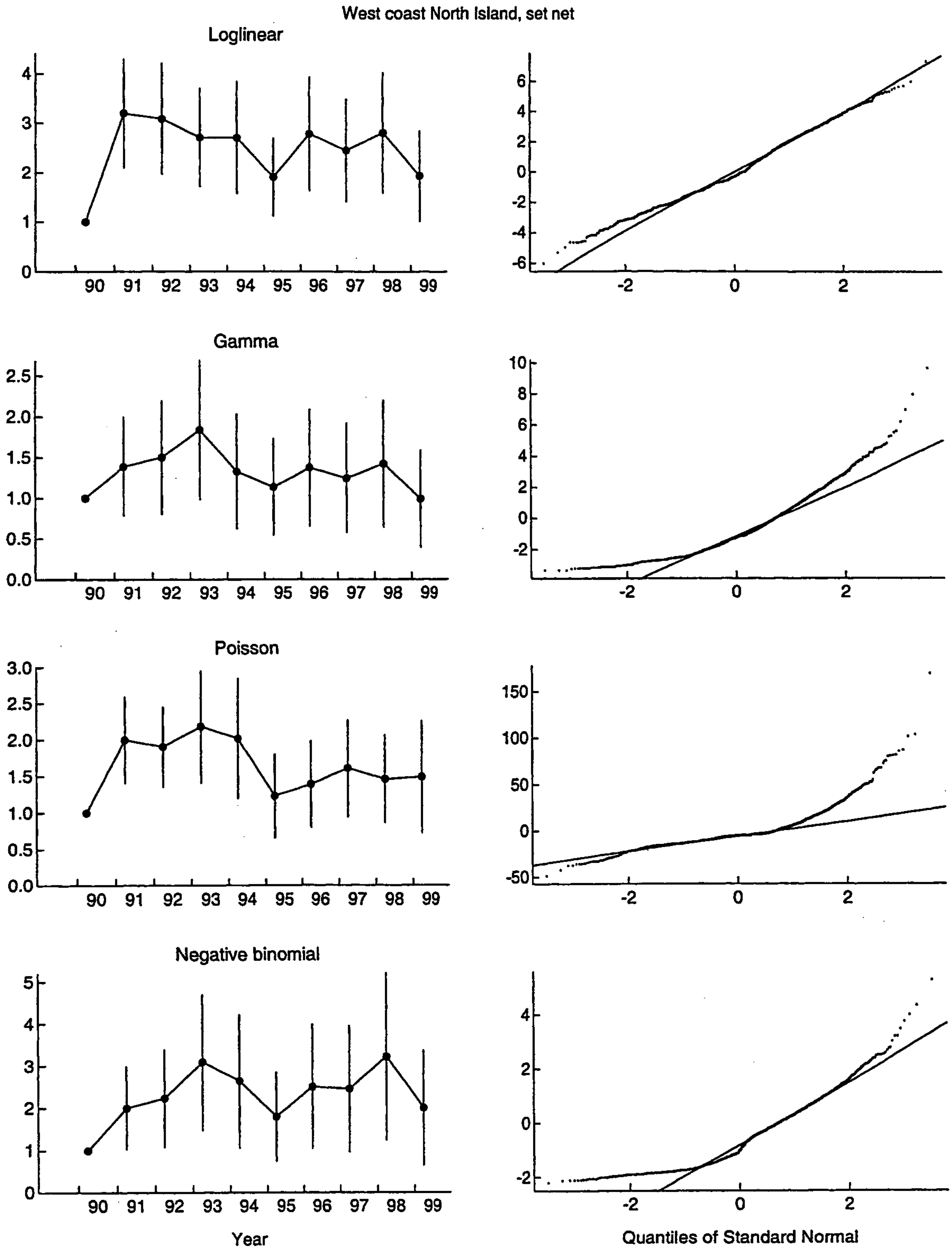

Figure 10a: As for Figure 5a but using data from the west coast North Island.

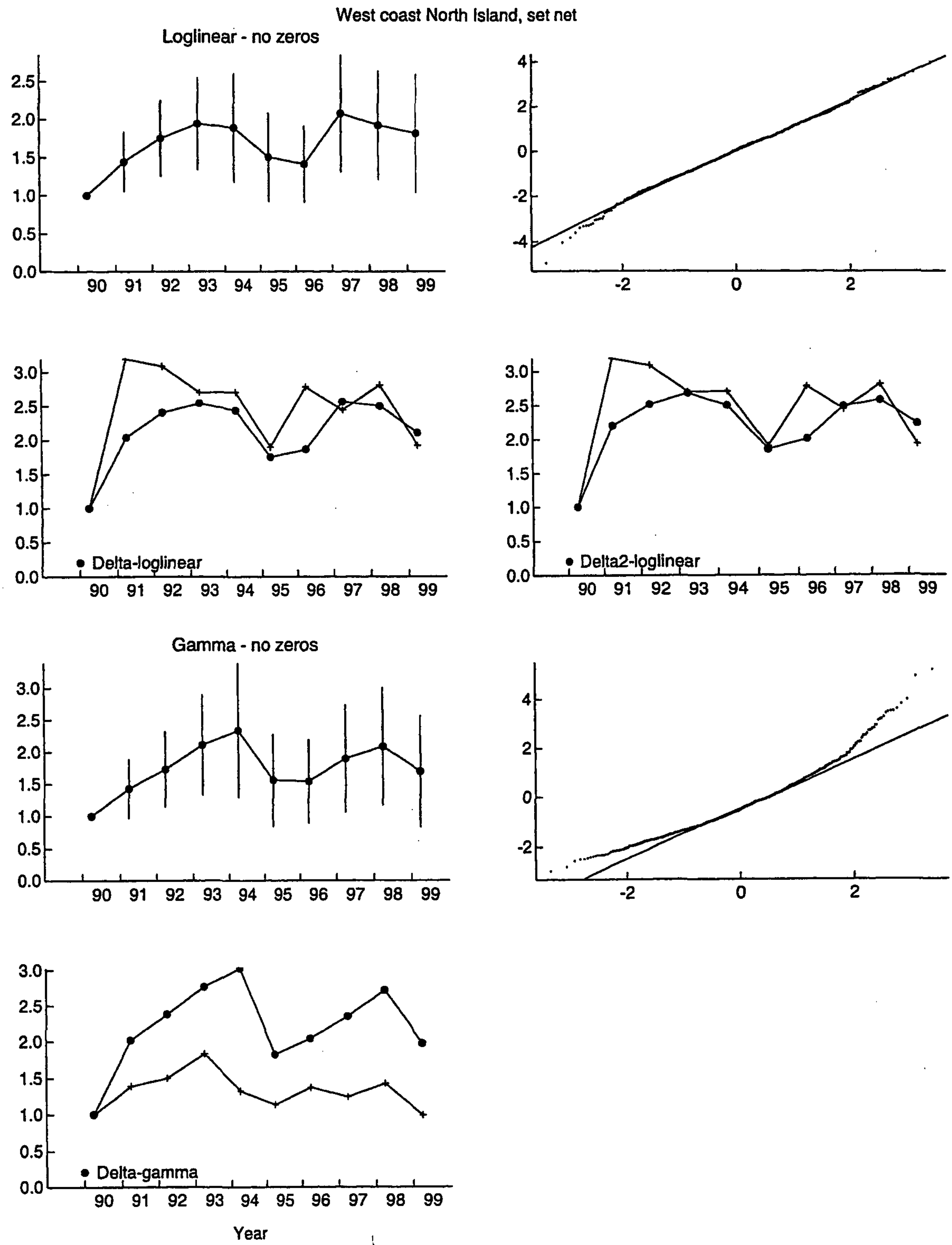

Figure 10b: As for Figure 5b but using data from the west coast North Island.

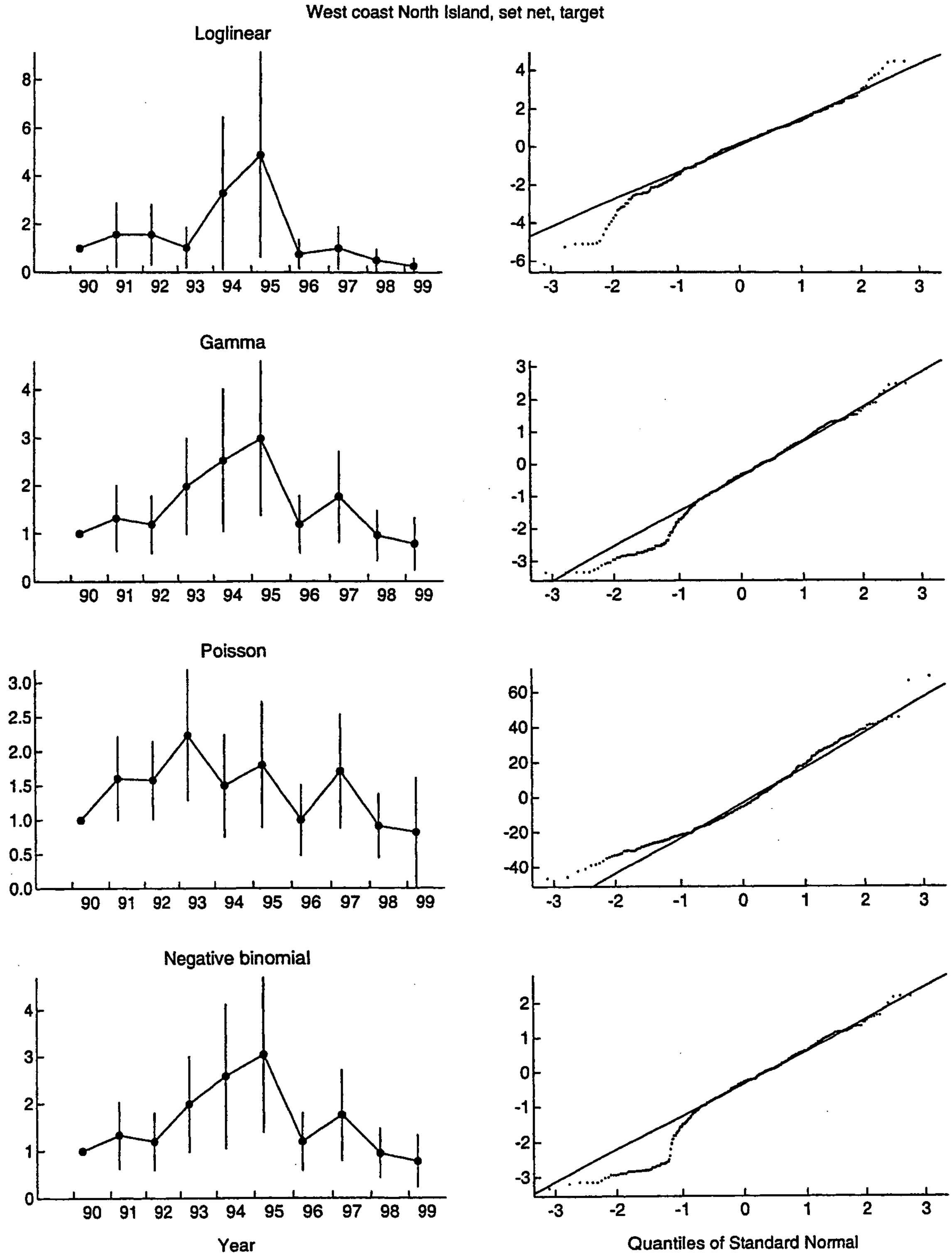

Figure 10c: As for Figure 5c but using data from the west coast North Island.

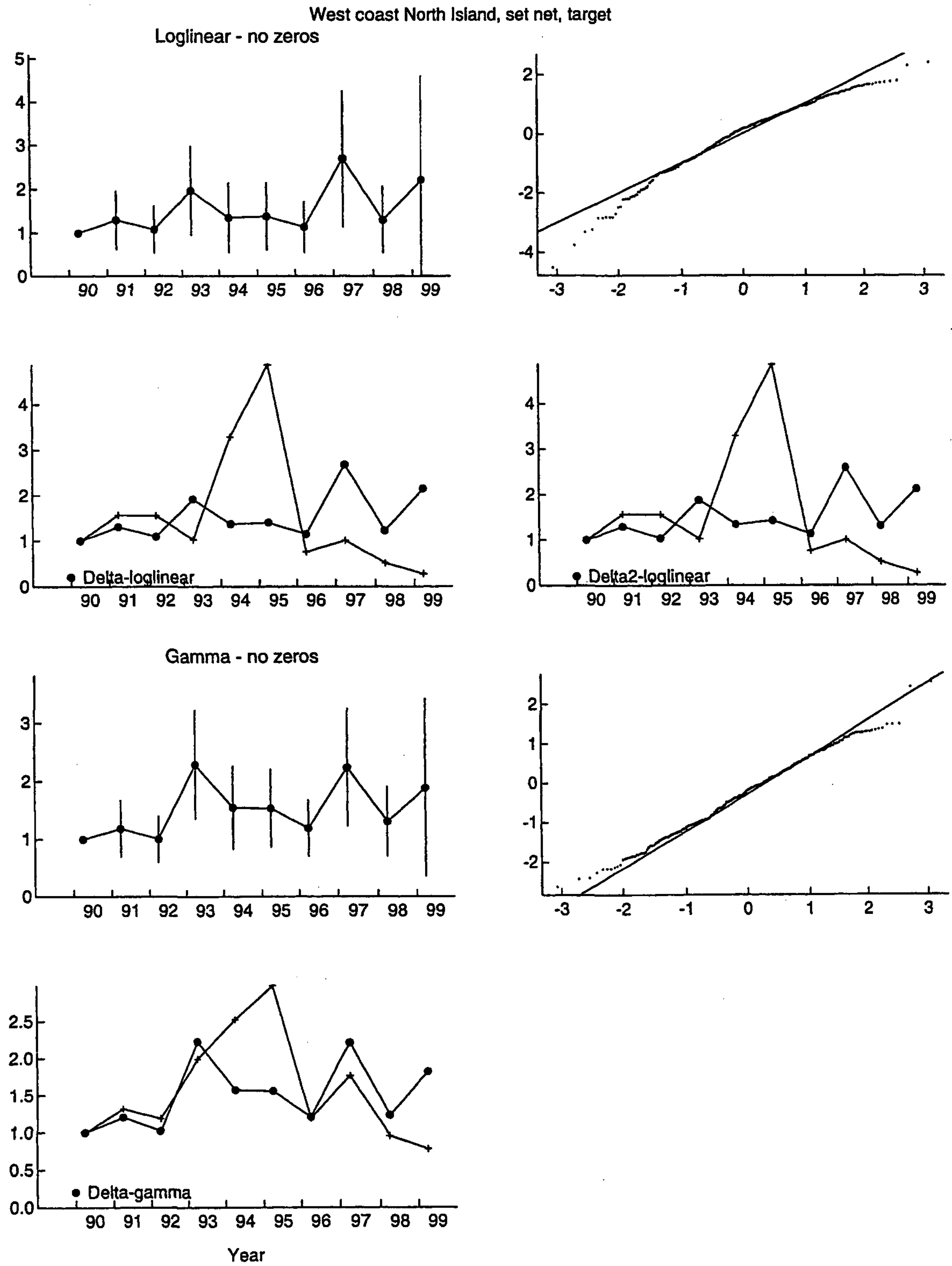

Figure 10d: As for Figure 5d but using data from the west coast North Island.

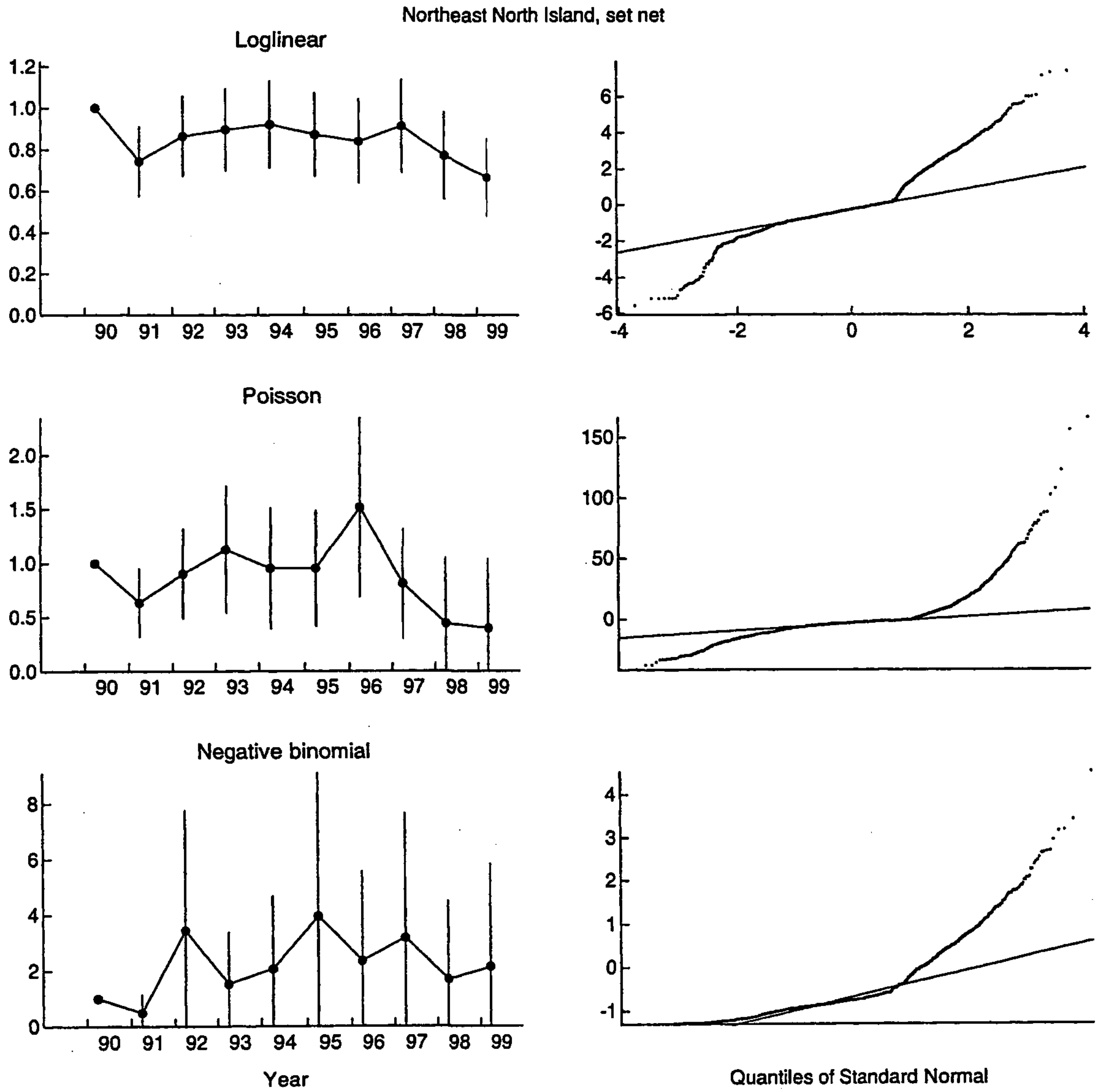

Figure 11a: As for Figure 5a but using data from the northeast North Island.

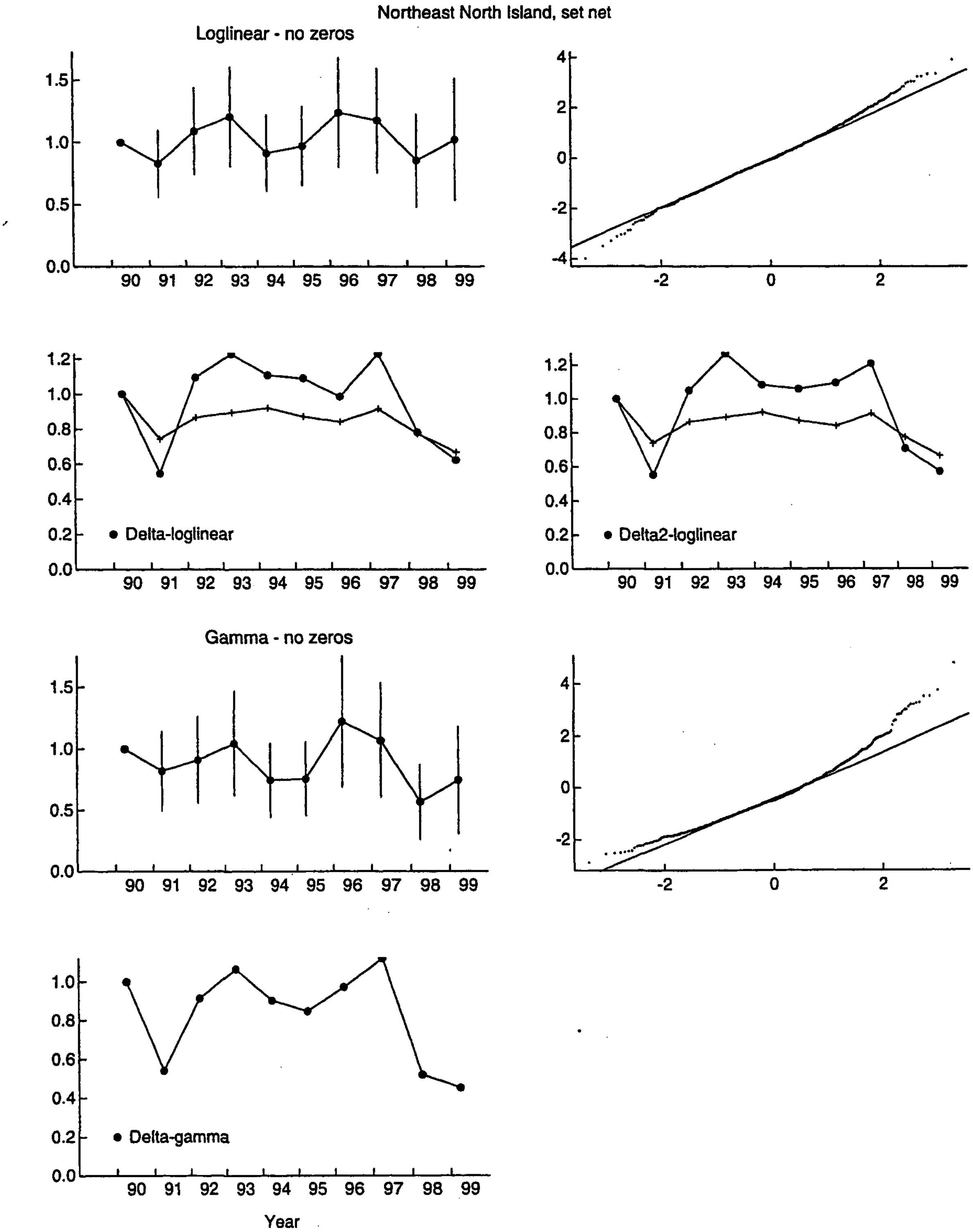

Figure 11b: As for Figure 5b but using data from the northeast North Island.

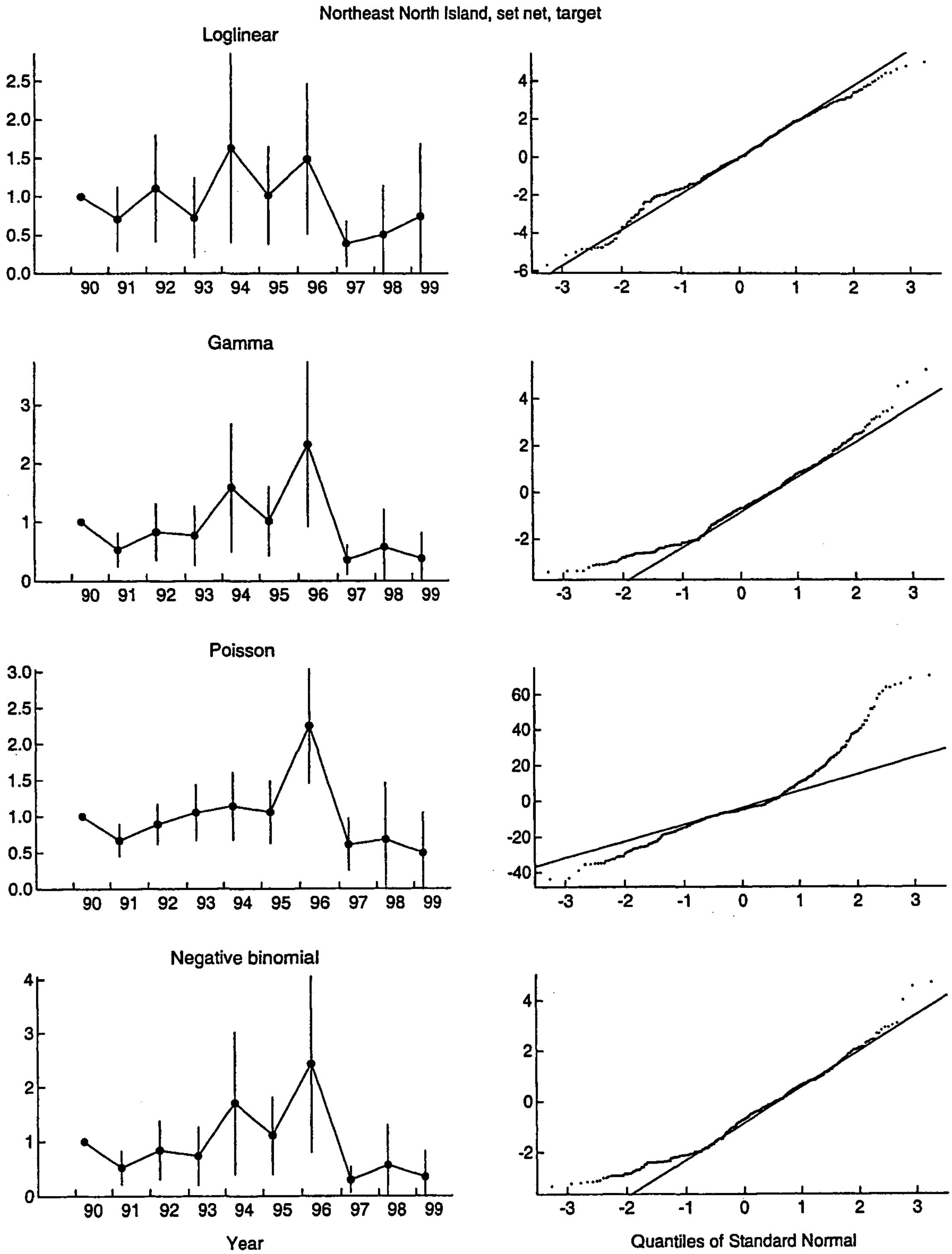

Figure 11c: As for Figure 5c but using data from the northeast North Island.

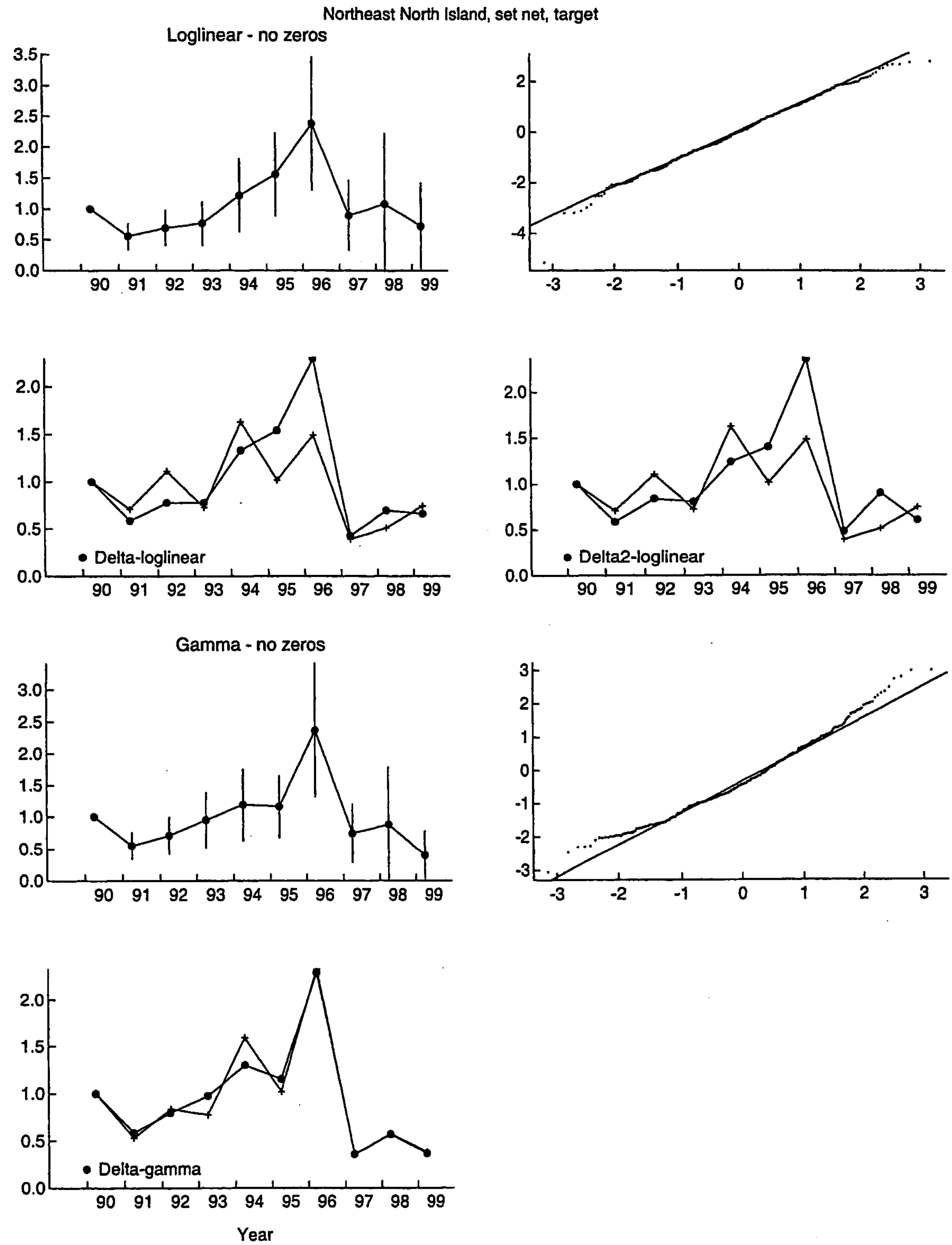

Figure 11d: As for Figure 5d but using data from the northeast North Island.

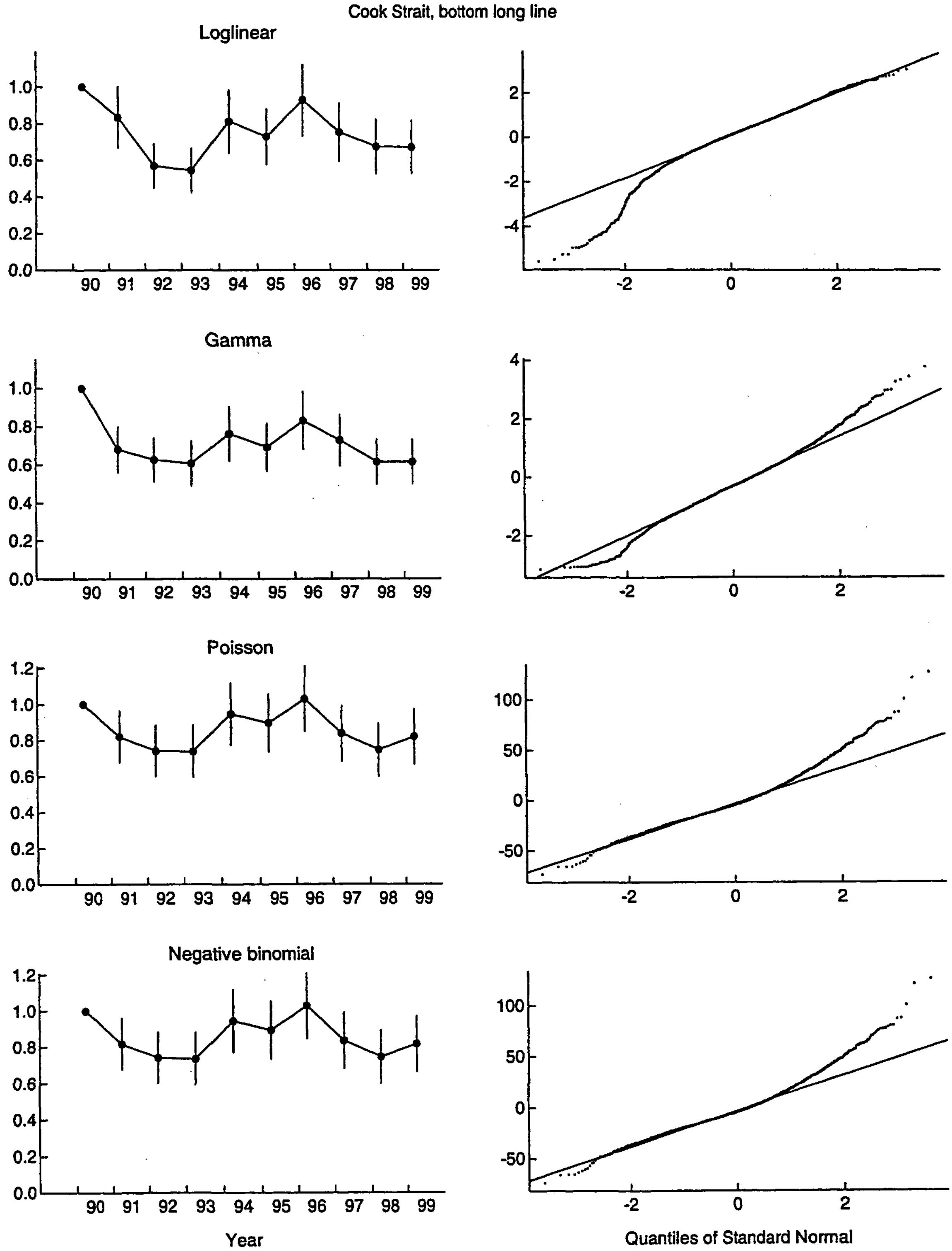

Figure 12a: Standardised catch rate indices and residual quantile-quanatile plots for those models for which solutions were obtained. The data used were from the Cook Strait bottom longline school shark target fishery.

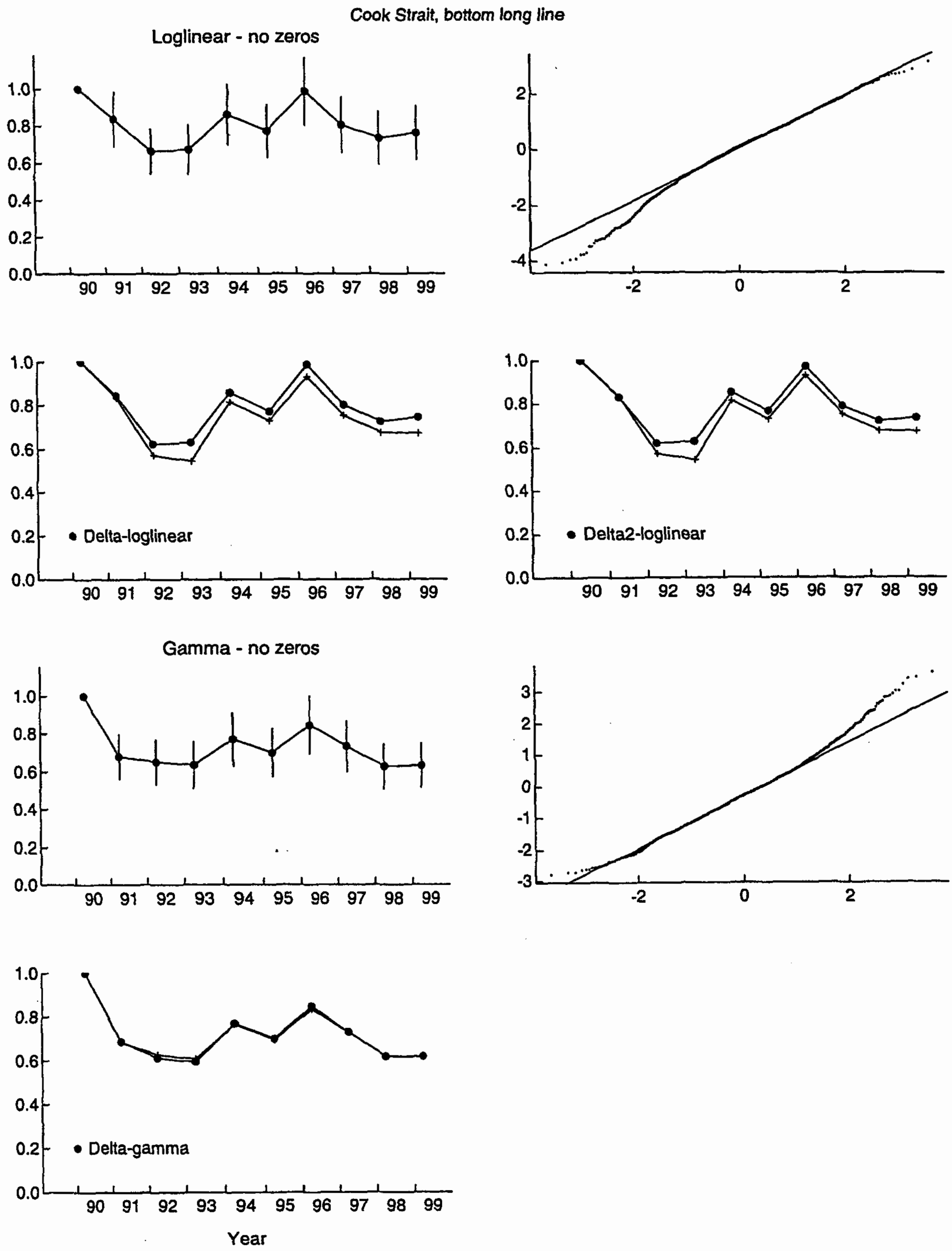

Figure 12b: Delta-X standardised catch rate indices. Where available, the comparison index is that for the model containing the zero catch rates, The data used were from the school shark target bottom longline fishery in Cook Strait.

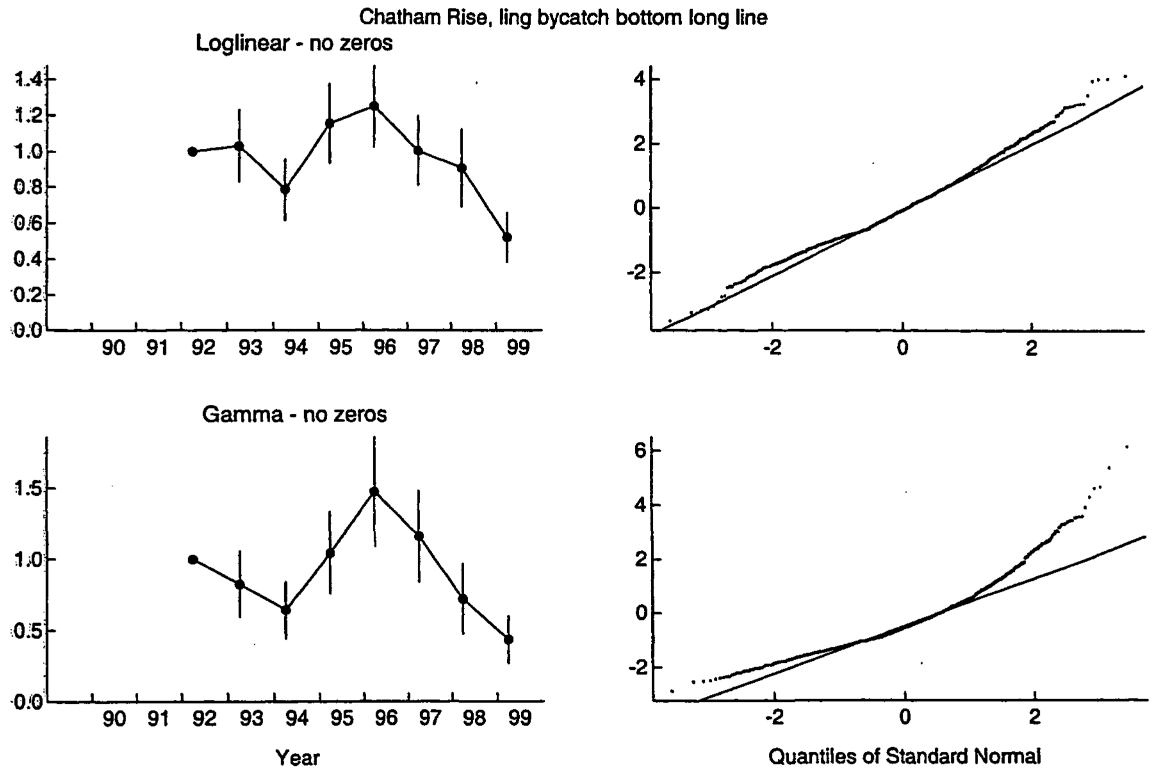

Figure 13: Standardised catch rate index and residual quantile-quantile plot for the loglinear and Gamma models without zeros. The data used were the school shark bycatch rates of the ling bottom longline fishery on the Chatham Rise.

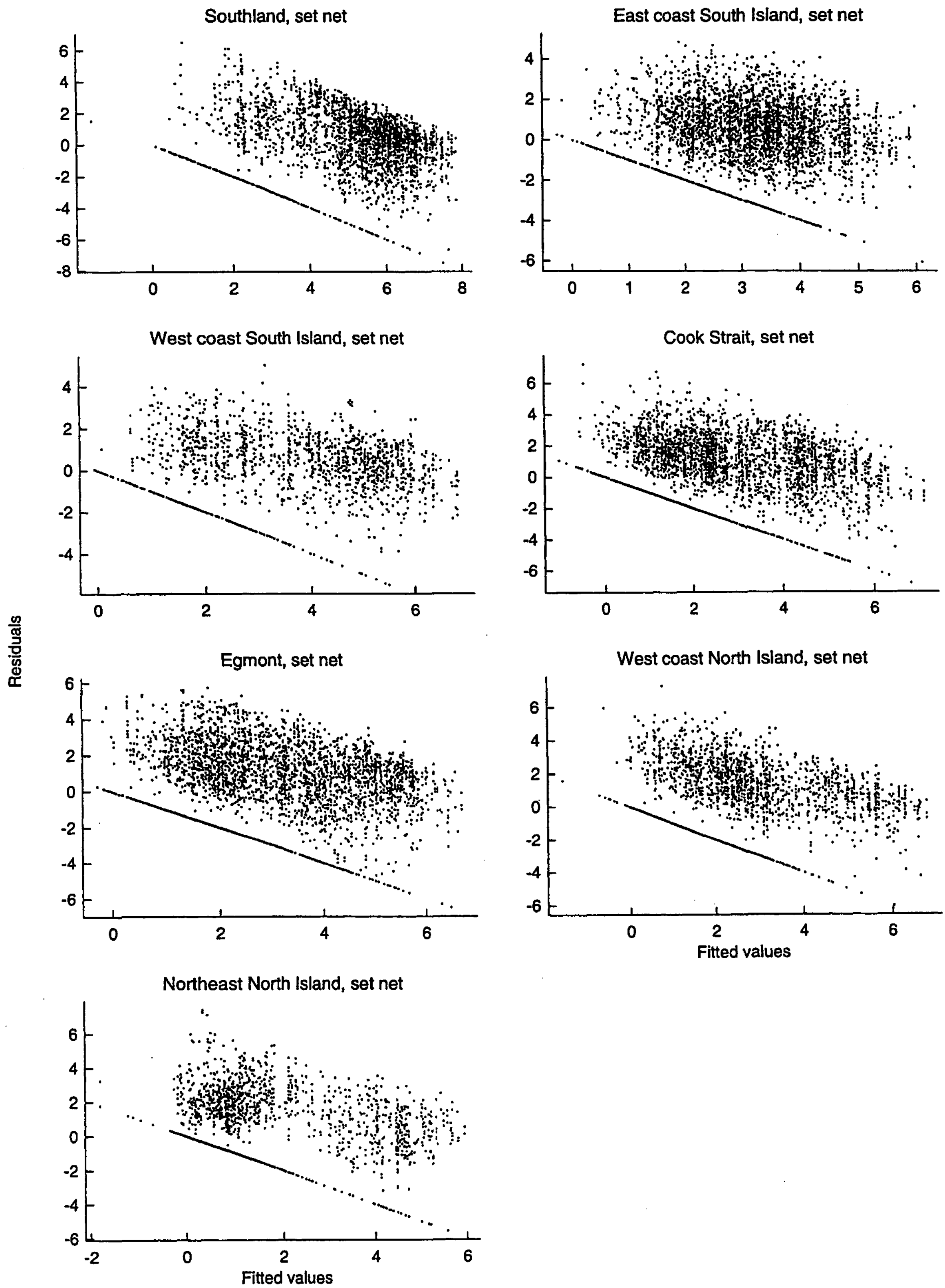

Figure 14: Plots of residuals versus fitted values for lognormal models for school shark and rig target set net data.

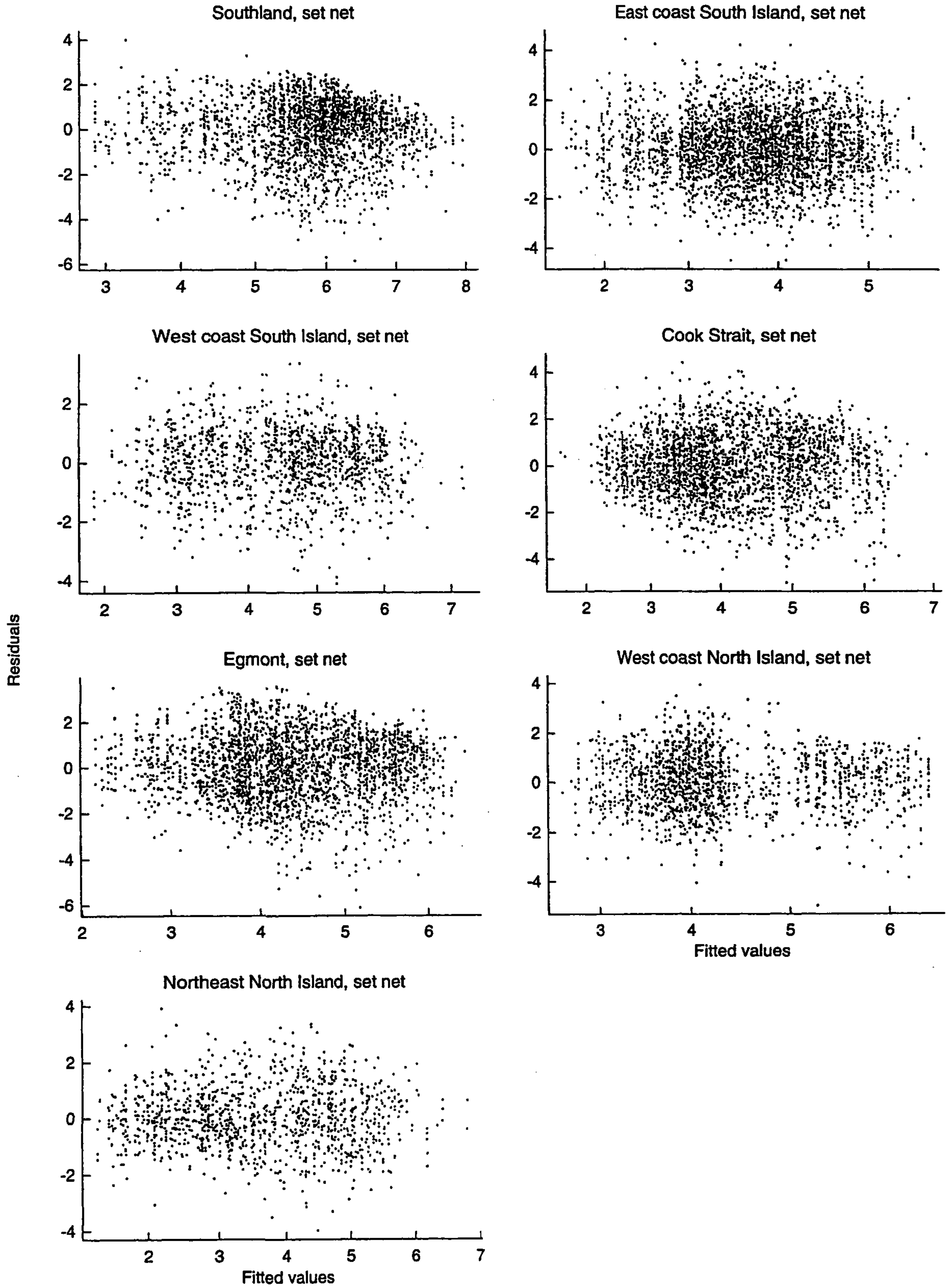

Figure 15: Plots of residuals versus fitted values for lognormal models without zeros for school shark and rig target set net data.

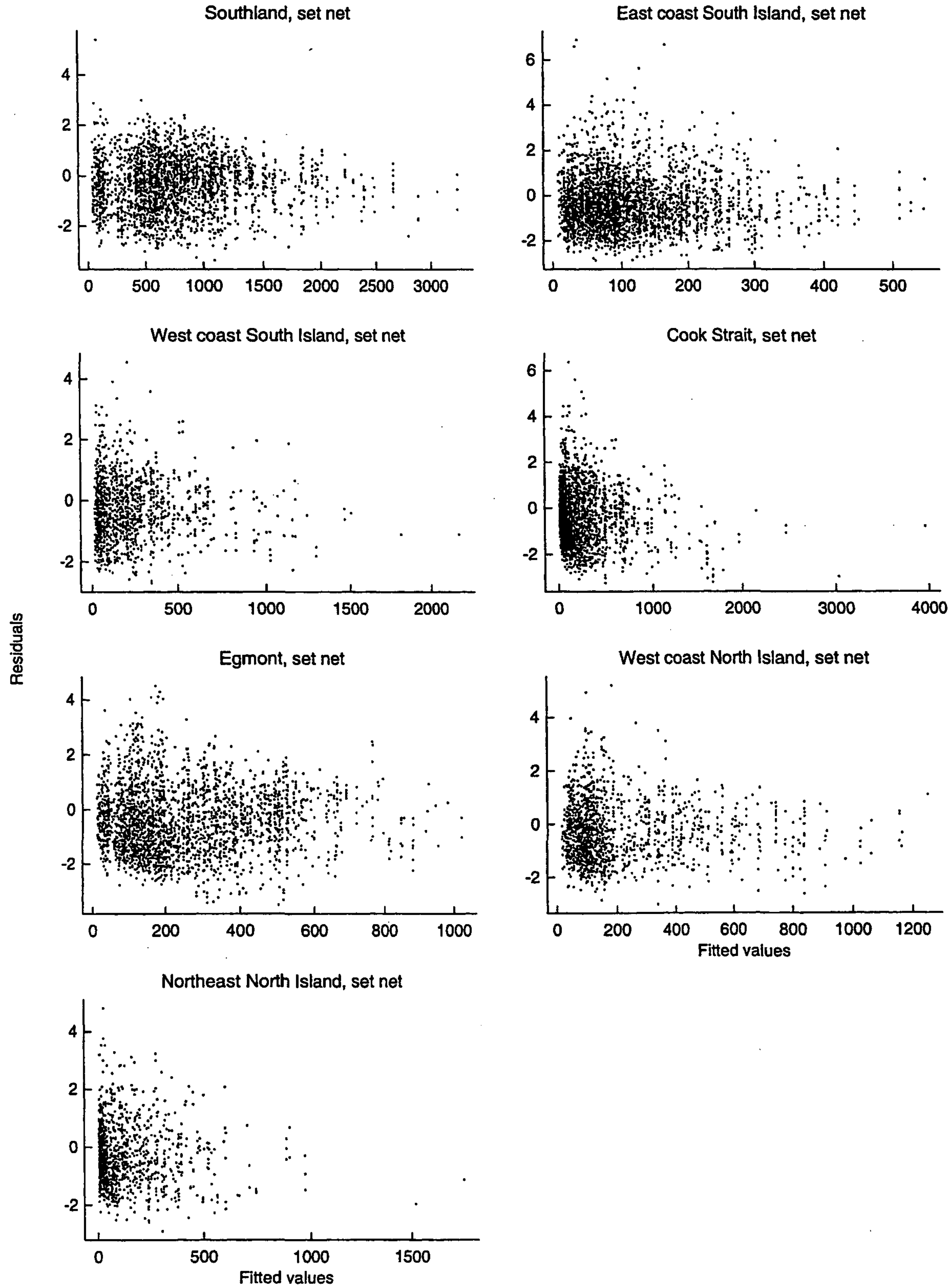

Figure 16: Plots of residuals versus fitted values for gamma models without zeros for school shark and rig target set net data.

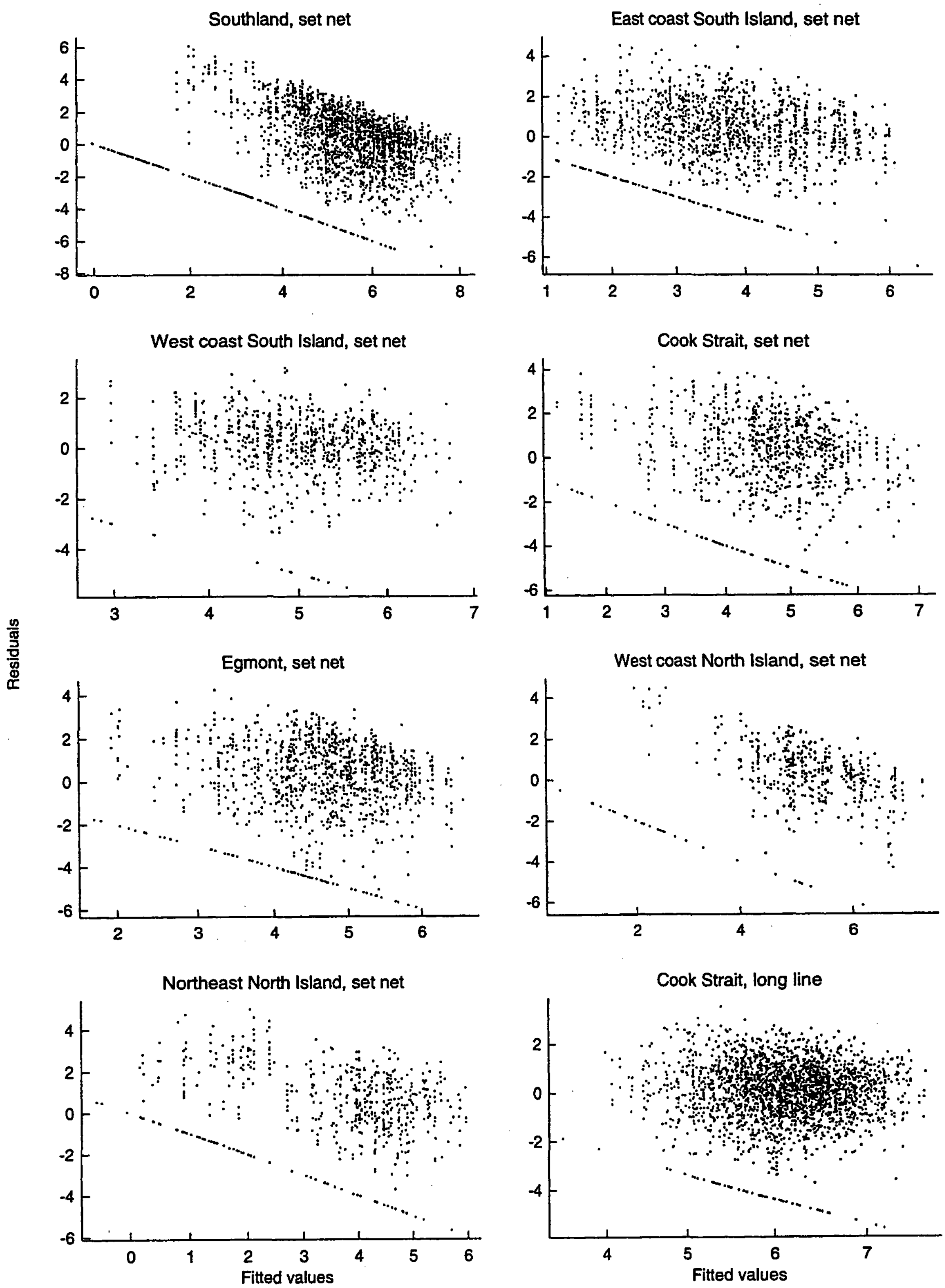

Figure 17: Plots of residuals versus fitted values for lognormal models for school shark target set net data.

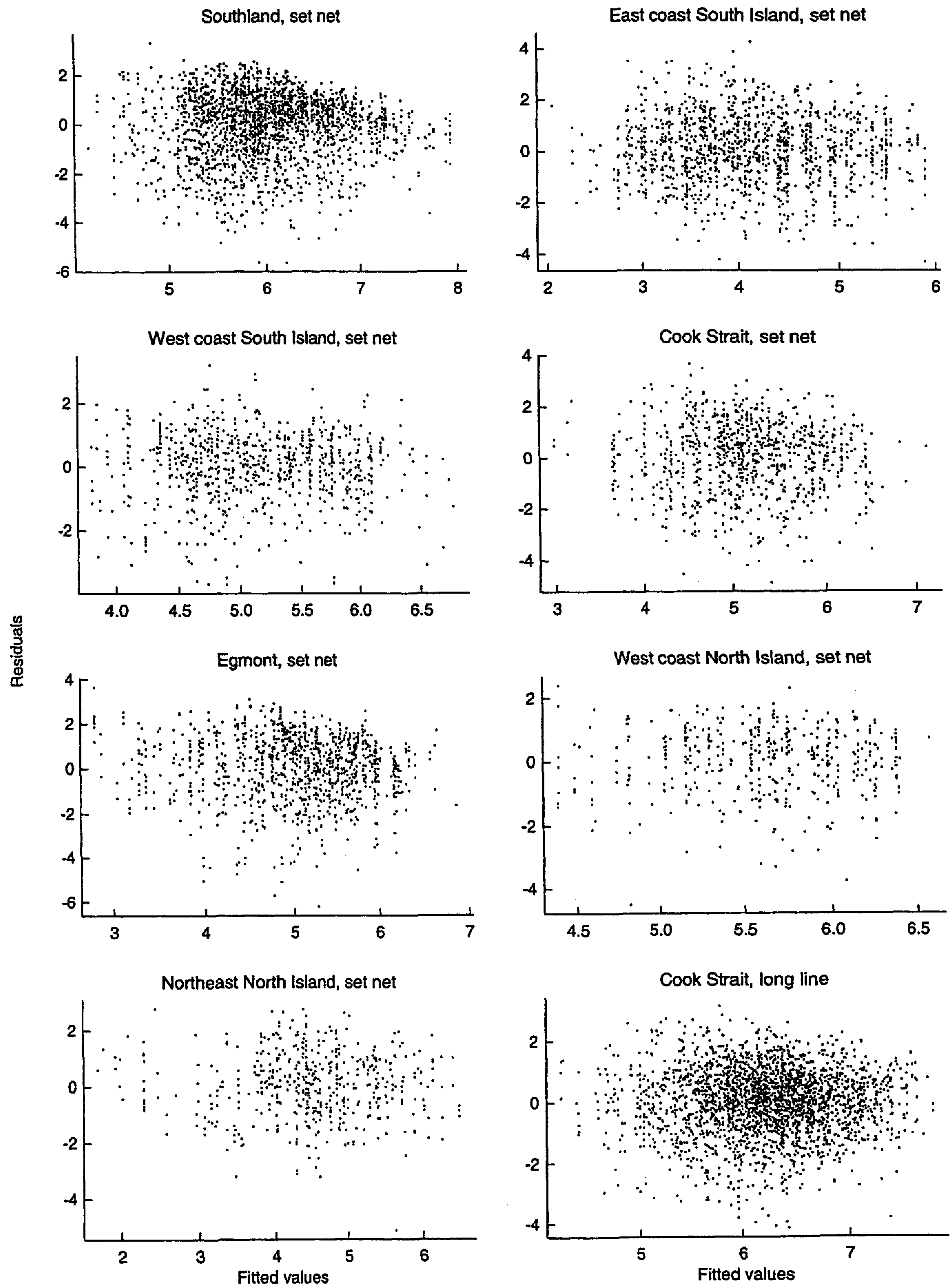

Figure 18: Plots of residuals versus fitted values for lognormal models without zeros for school shark target set net data.

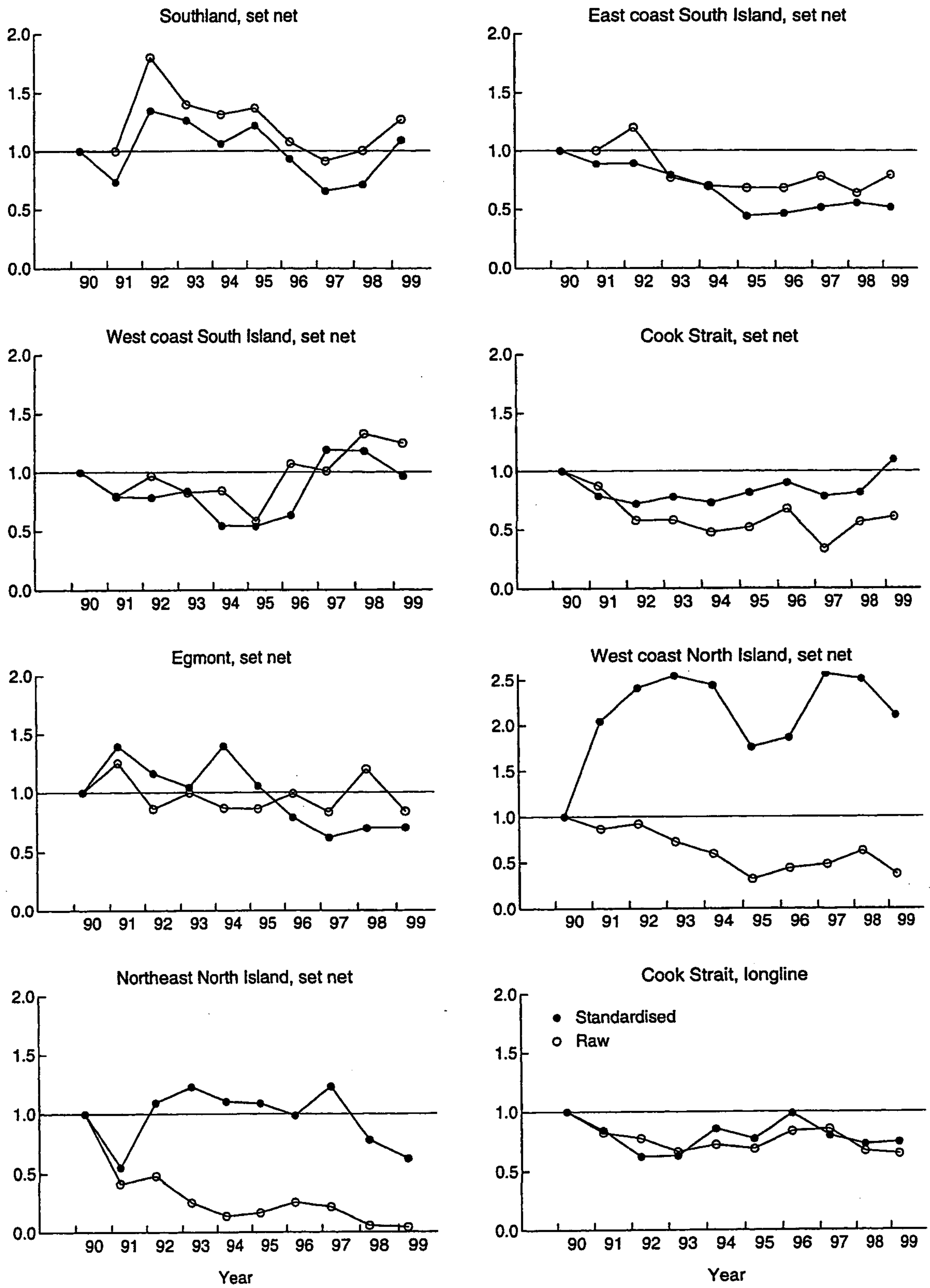

Figure 19: Comparison of "best" base case year indices for the seven regional set net fisheries and the Cook Strait bottom longline fishery. Raw catch rates calculated using the ratio-of-means estimator (relative to their 1989–90 value) are included.

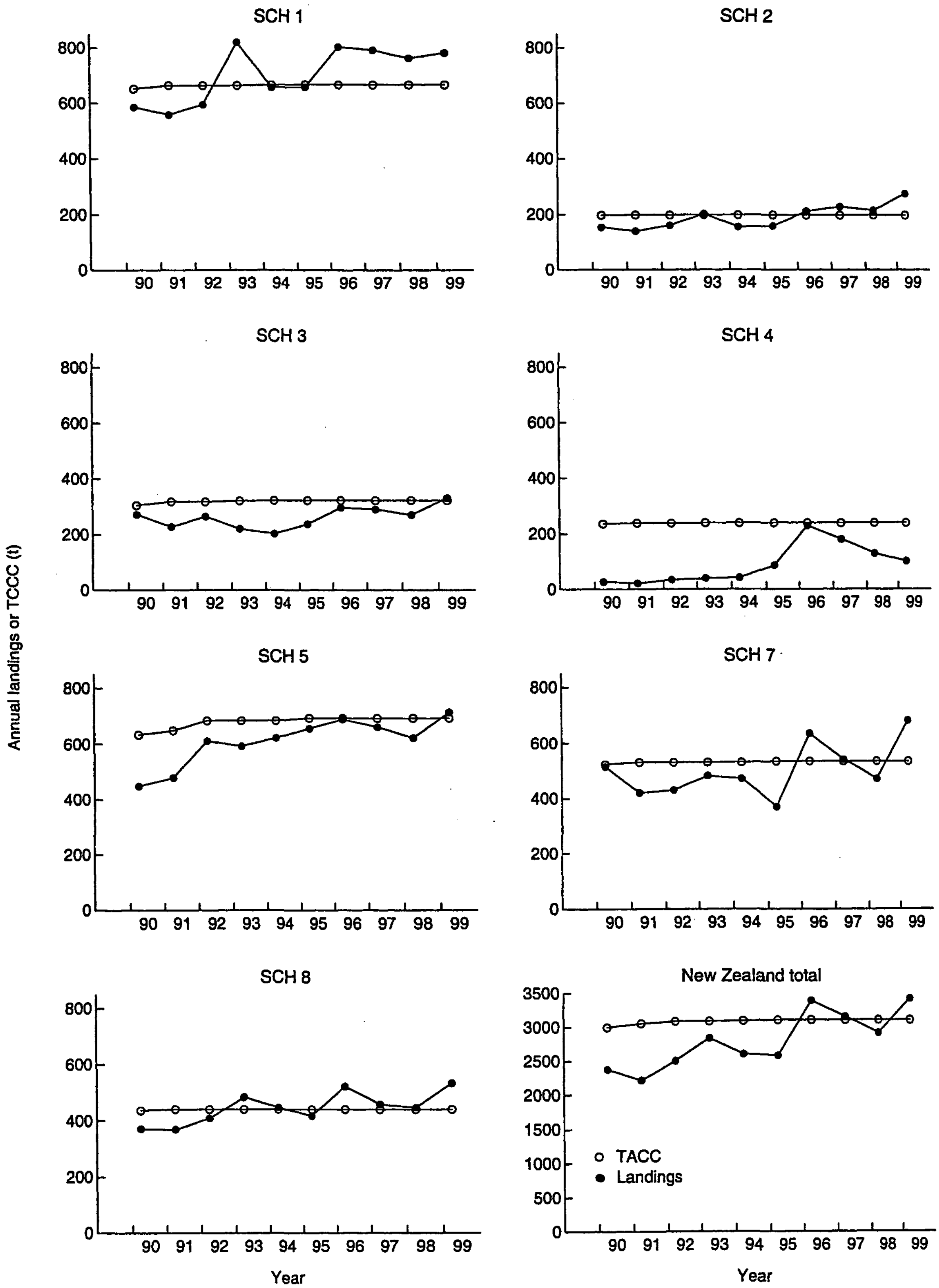

Figure 20: Landings and TACC for school shark by Fishstock for the past 10 years.

APPENDIX A: INDUSTRY LOG BOOK RESULTS

NIWA requested data from the industry log book scheme to see if they would aid in the interpretation of the standardised catch rates. Paul Starr and Adam Langley (SeaFIC) contacted the fishers concerned for their permission to allow NIWA access to the data. Most were agreeable (a few fishers could not be contacted) and the data shown here represent about 90% of that available.

Industry scientists have been running voluntary log book schemes in several fisheries to collect data that would be useful for monitoring and managing these fisheries and that were not collected adequately by the catch, effort, and landing returns made to the Ministry of Fisheries. Of interest here are log books from the shark fisheries around the east and south coasts of the South Island and in the Egmont area. Cook Strait data shown below are from Statistical Area 18 only and are not necessarily representative of the whole region.

Mesh sizes from all sets where school shark or rig was the target species were extracted for comparison with those from the CELR forms (Figure A1, to be compared with Figure 2). The mesh sizes from the industry log books were less variable than those from the CELR forms, but the main peaks agree, except on the east coast South Island where the CELR forms apparently had more mesh sizes around 175 mm than the industry log book data. It is possible that there has been a general reduction in mesh size used in this region over the 10 years for which CELR data are available. (Mesh size was the most noticeably error prone field on the CELR forms.)

Depth of set information is available from the Industry log book scheme, but not from the CELR forms (Figure A2). Depth information is likely to be useful in defining the extent of the school shark fishery and as an explanatory variable in the catch rate standardisation. In Southland, sets were made out to depths of 150 m, and on the east coast of the South Island out to just over 100 m with most sets being in depths up to 50 m. There were too few data points in the other regions to define the depth distributions but they seem to be between 100 and 150 m in Statistical Area 18, and to be less than about 70 m in Egmont.

The industry log book scheme collects biological information about the sharks caught. Of course, this includes fish sizes and these were plotted by region and fishing year in all cases where there were and adequate number of values (Figure A3). Lengths are rounded to the nearest 5 cm. In Southland, the sharks had a modal size of 135–140 cm with little change from year to year. On the east coast of the South Island, the main modal peak was at about 100 cm with a subsidiary peak of mainly females at around 150 cm, again there were only minor changes over time. In Cook Strait (Statistical Area 18) these sizes were spread over about 100 cm, except in 1997–98 when there were a small group of mainly males of about 100 cm and a larger group of mainly females of about 140 cm. The latter plot shows that school sharks can form single sex schools. The sample from Egmont is small but suggests that several schools were sampled.

Hurst *et al.* (1999) plotted size distributions of tagged sharks by QMA. Most school sharks released were tagged opportunistically during Ministry of Fisheries research bottom trawl surveys. Their distributions show a somewhat lower mode in Southland than the industry data and more large sharks caught on the east coast of the South Island than in the industry data. The different size selectivities in the trawl and set net fisheries are obviously effecting the size distributions.

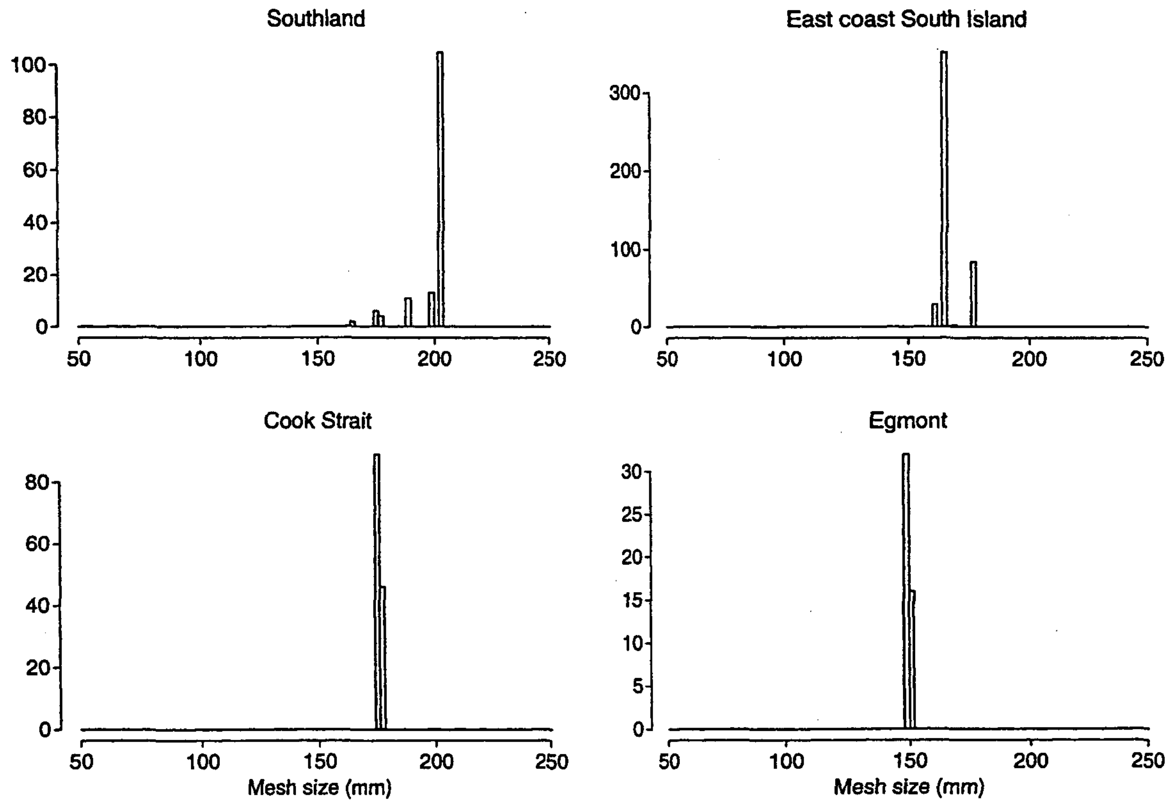

Figure A1: Mesh sizes used in the shark fishery (school shark or rig as target) by region from the industry log book data. The Cook Strait data are from Statistical Area 18 only.

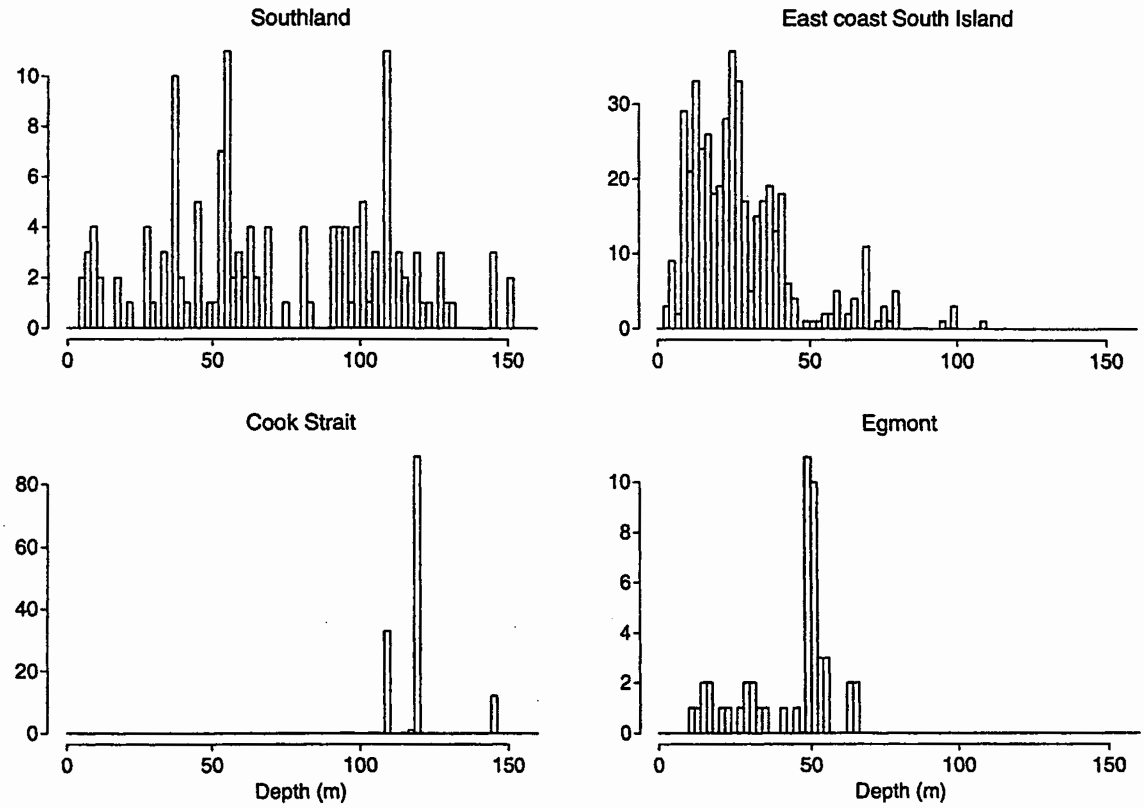

Figure A2: Start of set depths by region for the shark fishery (school shark or rig as target) from the industry log book data. The Cook Strait data are from Statistical Area 18 only.

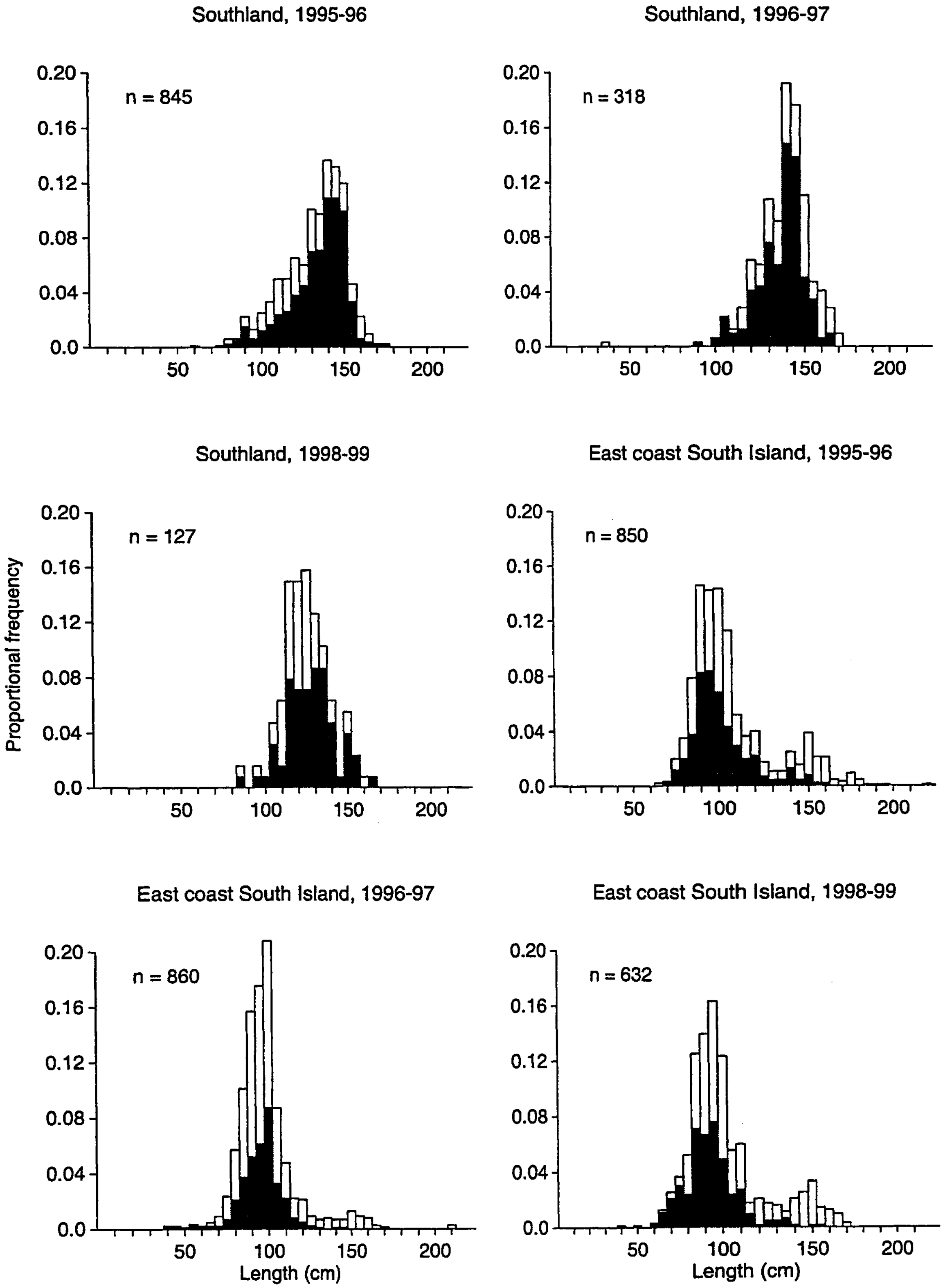

Figure A3: Size distributions by school shark fishery region and fishing year from industry log book data. Males are shaded, females are not.

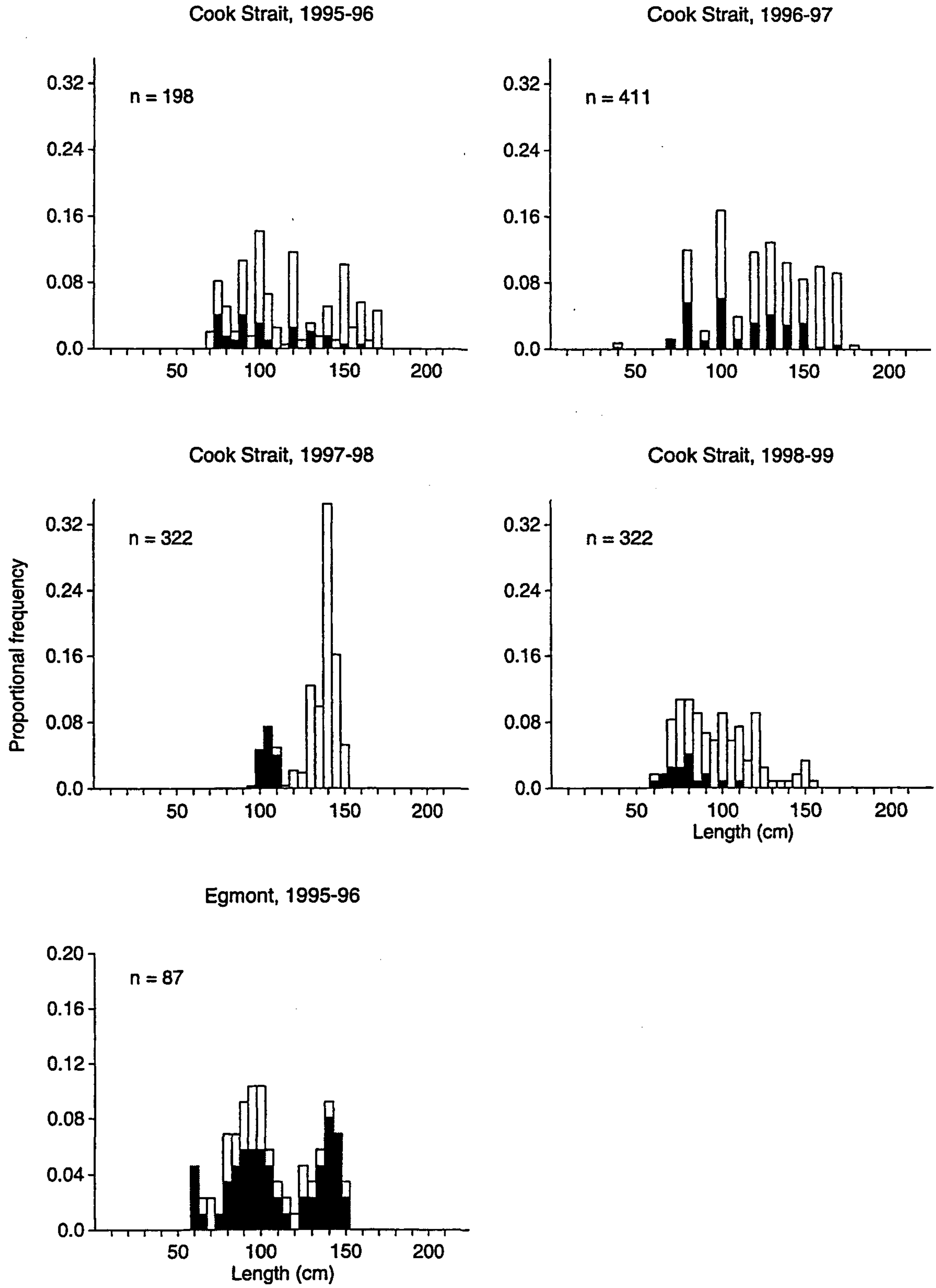

Figure A3: continued.

APPENDIX B: RAW CATCH RATES FROM FSU AND CELR DATA

Ten years is too short to detect whether there are any long-term trends in the school shark catch rates. From 1983, fisheries catch and effort data were collected by the FSU programme. Raw data from this period are not easily available. However, monthly total catch and effort data are available by vessel and fishing method. These FSU values will include school shark catches from set nets or bottom longline where non-shark species were the target. School shark catch rates should be lower in non-shark fisheries and will lower the mean catch rate. The CELR data are for target shark fisheries.

Raw catch rates have been estimated by region as annual total catch divided by annual total effort, that is, using a ratio-of-means estimator (as is done in recreational fisheries when considering total extractions by a fishery). This definition allows some compatibility between the FSU and CELR data, but the types of trips contributing are different (*see* above). Records with a monthly catch for a vessel of less than or equal to 20 kg were removed from the FSU data (this makes little difference); the CELR data were those used in the standardisations (so have rig-only and opportunistic vessels removed). Net lengths of less than 350 m or hook numbers less than 100 were removed from both sets of data.

Catch rates from the FSU are suspect in fishing years 1986–87 to 1987–89 due to incomplete reporting and data checking during these years.

The raw catch rates do not suggest long term increasing or decreasing trends, except perhaps in the northeast of the North Island. Usually, the general level of catch rate is greater from the CELR data than the FSU data, as might be expected from the differences in how the data were selected. The difference between the FSU and CELR levels is possibly greater than might be expected in Cook Strait (both set net and bottom longline) and Egmont. These raw catch rates from the CELR data were compared with the standardised catch rates (*see* Figure 19).

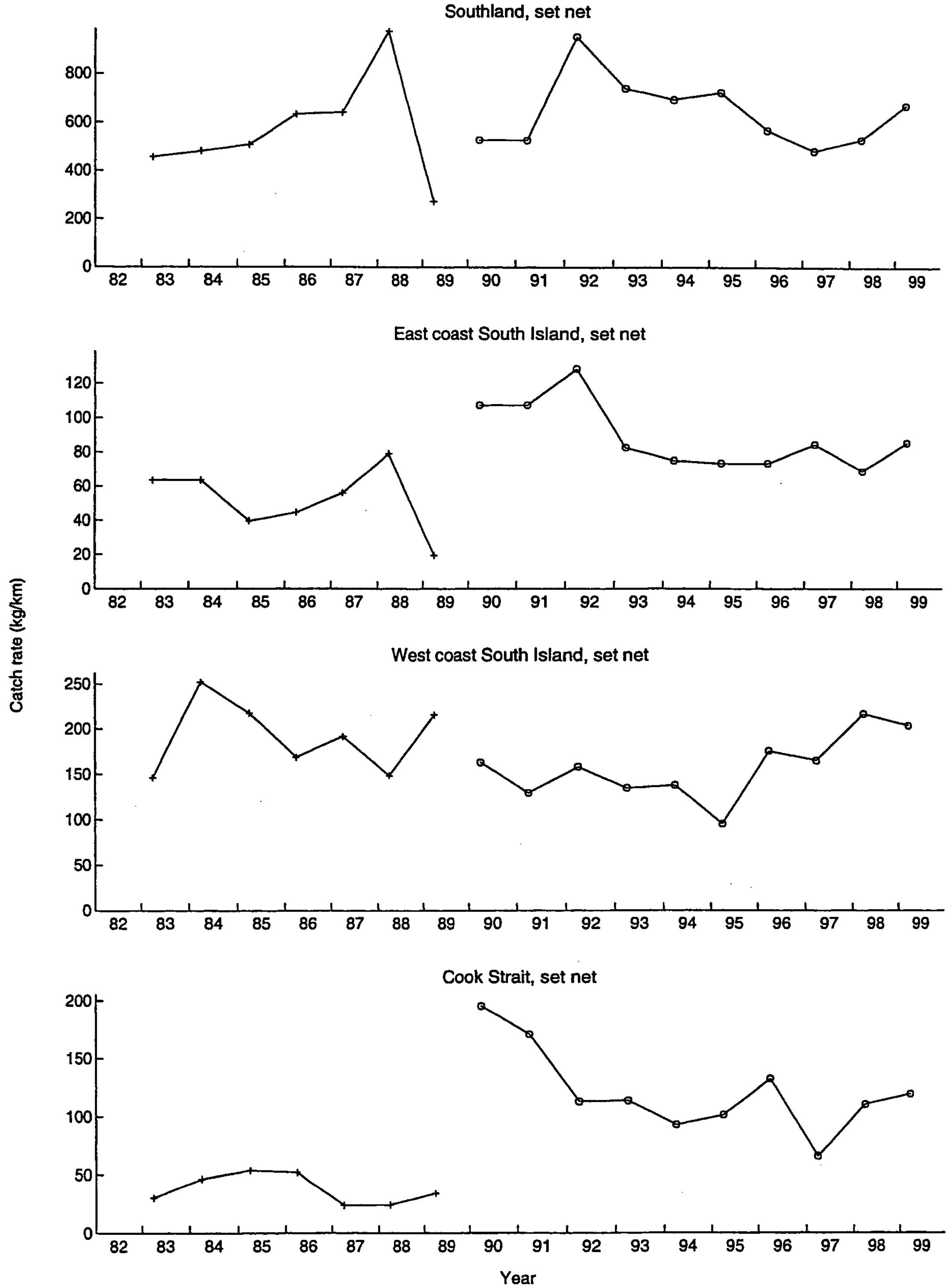

Figure B1: Raw catch rates from the school shark set net fishery by region using FSU and CELR data. The data from the last three years of the FSU are suspect due to incomplete reporting.

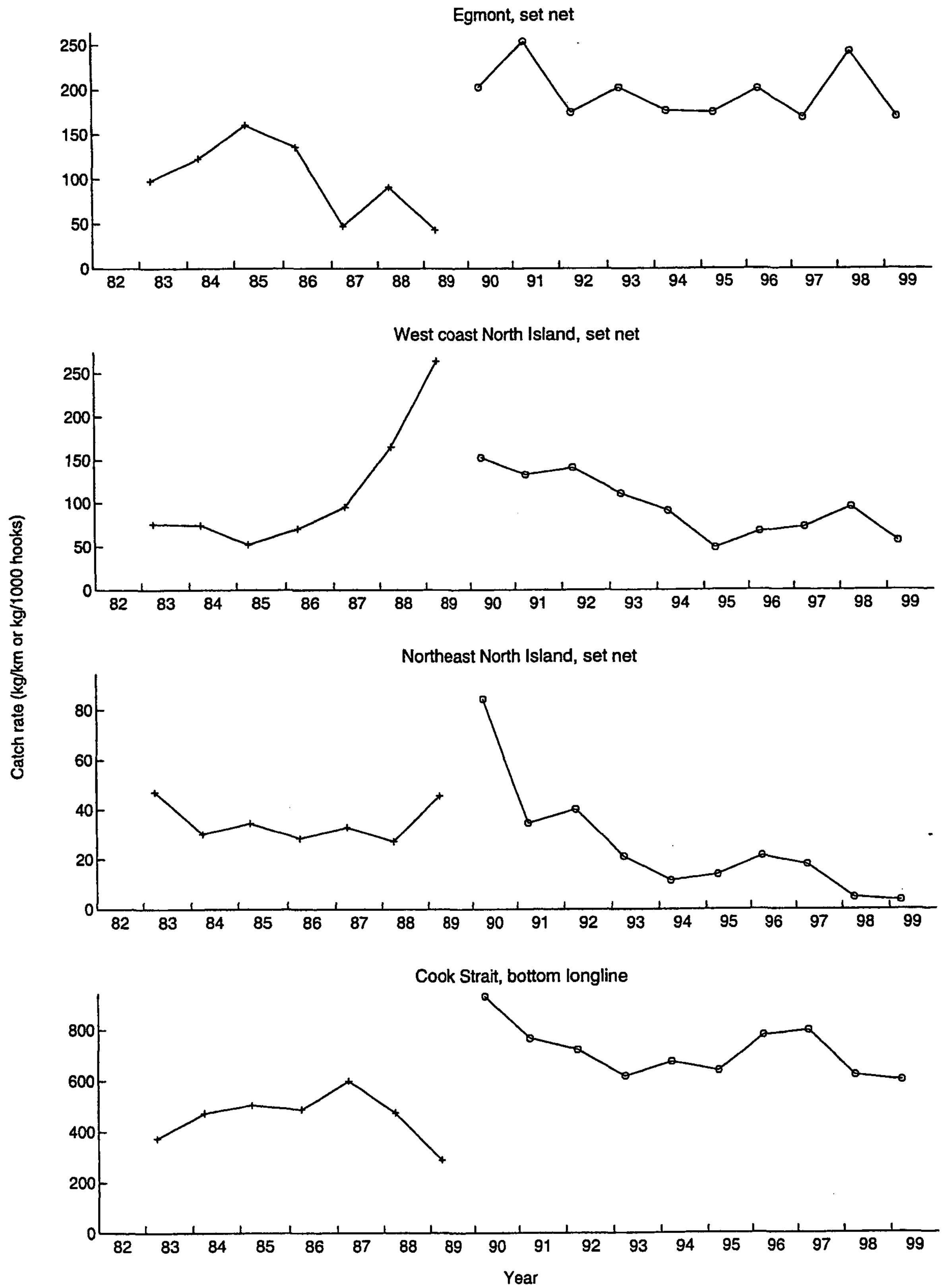

Figure B1: continued