upward trend after 1995 is not thought to reflect a change in fishing methods as domestic vessels replaced Japanese longliners. It is not clear whether this is merely fluctuation at low levels or local improvement from an historically low abundance level. The CPUE trend in the New Zealand EEZ is certainly consistent with declines seen elsewhere for this stock. The magnitude of the decline is also consistent with the hypothesis that abundance of the bigeye stock is exhibiting more rapid changes at the extremes of its geographical distribution.

5. Acknowledgements

The research reported here was supported by the New Zealand Ministry of Fisheries under contract through NIWA Project TUN9701. The authors gratefully acknowledge this support.

6. References

Anon. 1998. Report of the eleventh meeting of the Standing Committee on Tuna and Billfish, 28 May — 6 June 1998, Honolulu, Hawaii, USA. Iii + 108 pp. Secretariat of the Pacific Community, Noumea, New Caledonia.

Miyabe, N. and Y. Takeuchi. 1998. Exploring VPA analysis on Pacific bigeye tuna. SCTB11/WP.16; 16pp.

Richardson, K. M., Murray, T., Dean, H. 1998. Models for Southern Bluefin Tuna in the New Zealand EEZ. CCSBT-SC/9807/16.

Sun, C.-L. and S.-Z. Yeh. 1998. Standardised CPUE of central and western Pacific bigeye tuna from Taiwanese longline fisheries. SCTB 11/WP.20, 8pp.

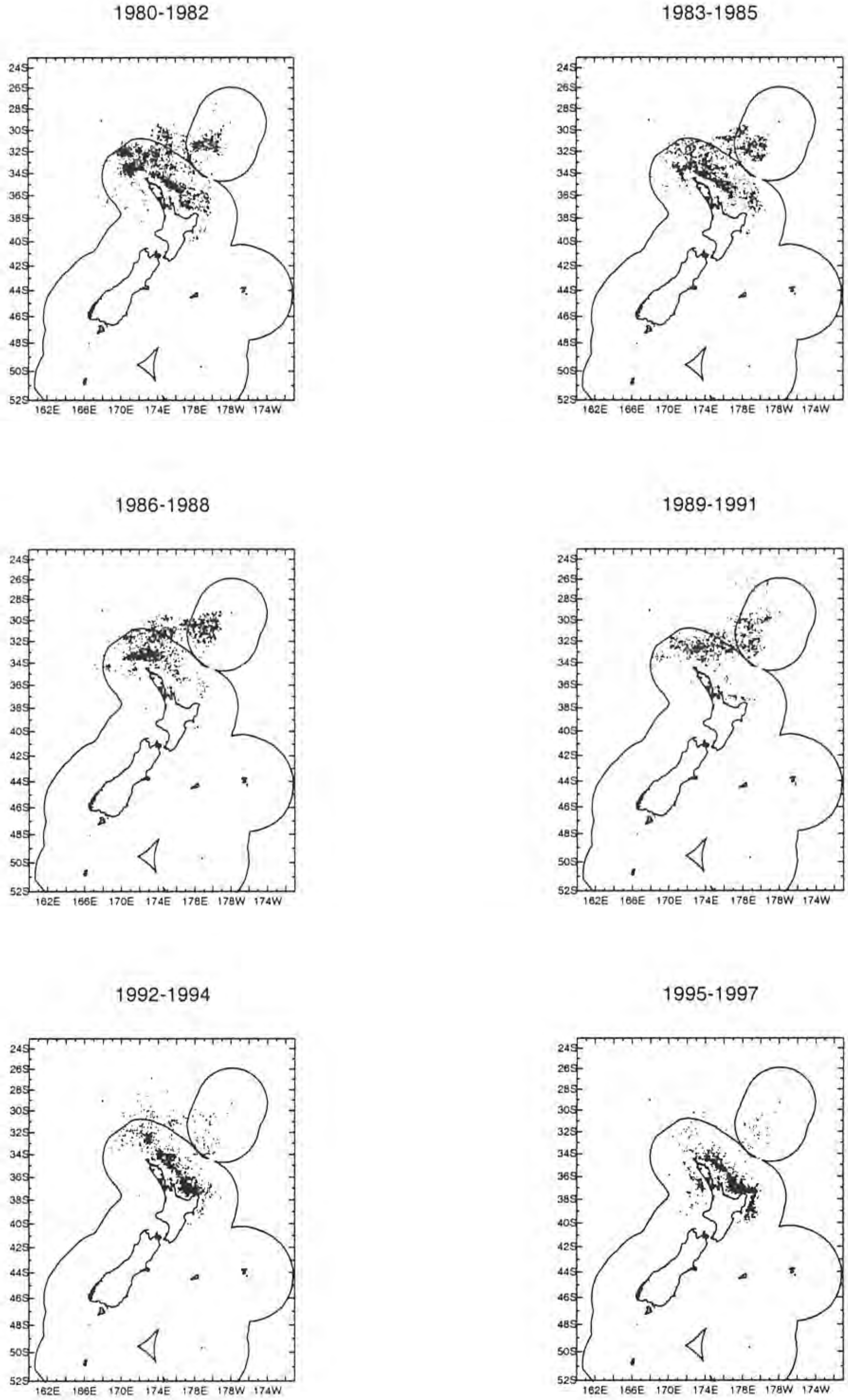

Figure 1 Map of New Zealand waters showing the positions of sets targeting bigeye in three year intervals over the period 1980-1997.

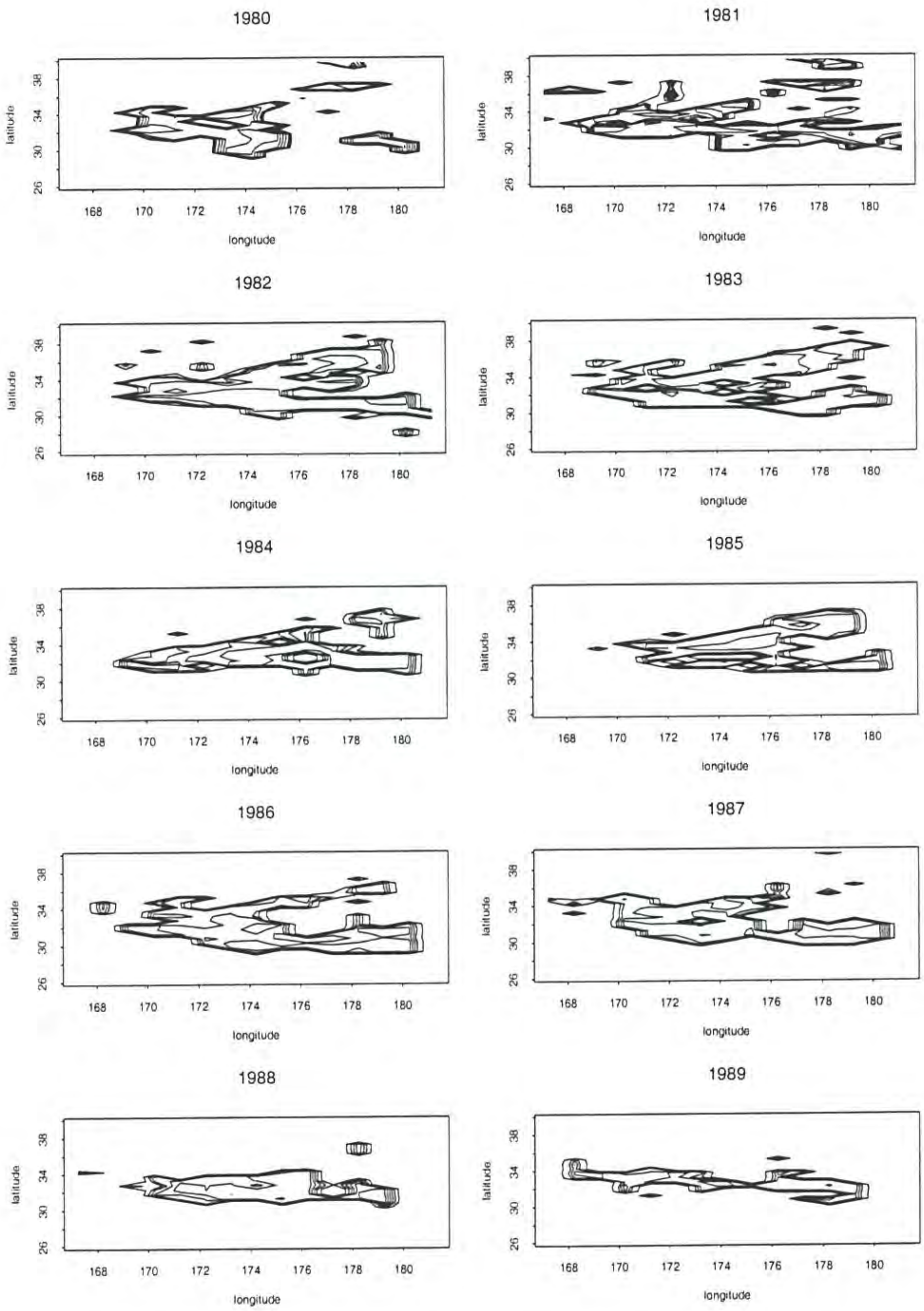

Figure 2a: Contour plots of $\log(CPUE + \delta)$ for the same area as in Figure 1 for data in 1980-1989

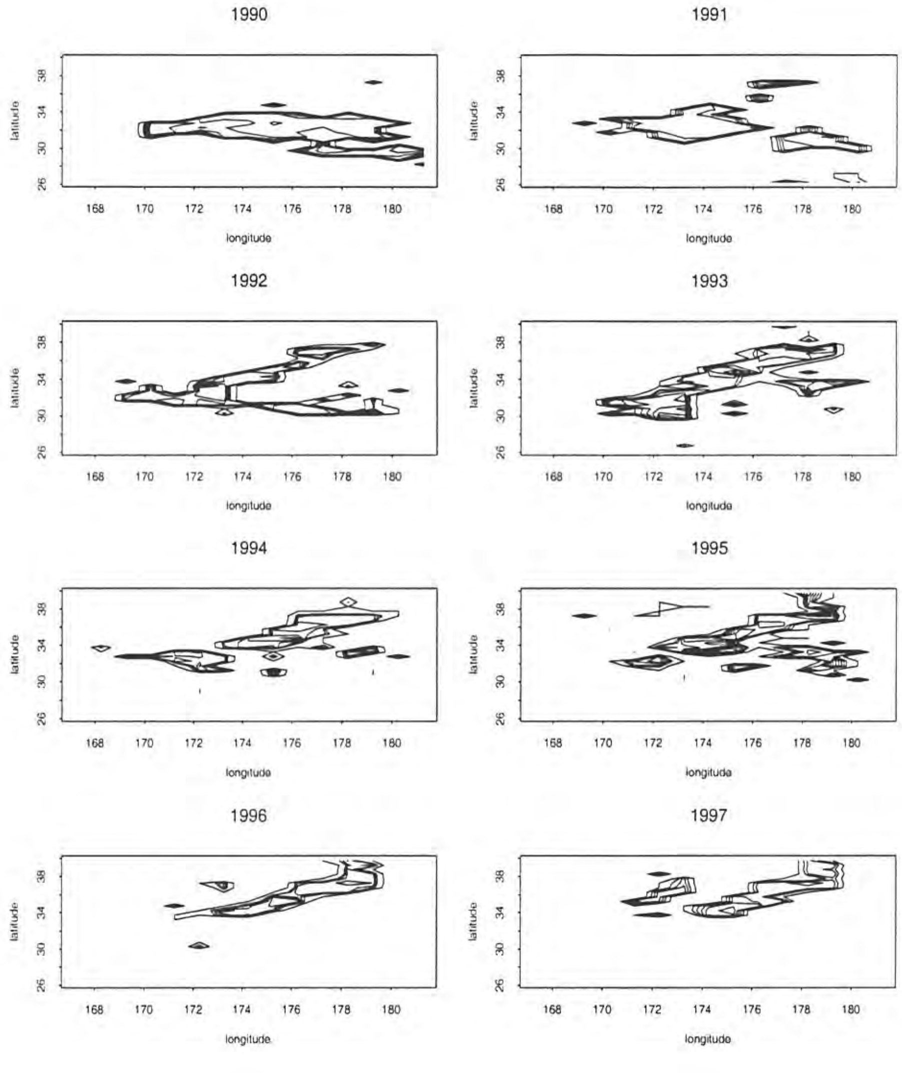

Figure 2b: As in Figure 2a, except data plotted for years 1990-1995

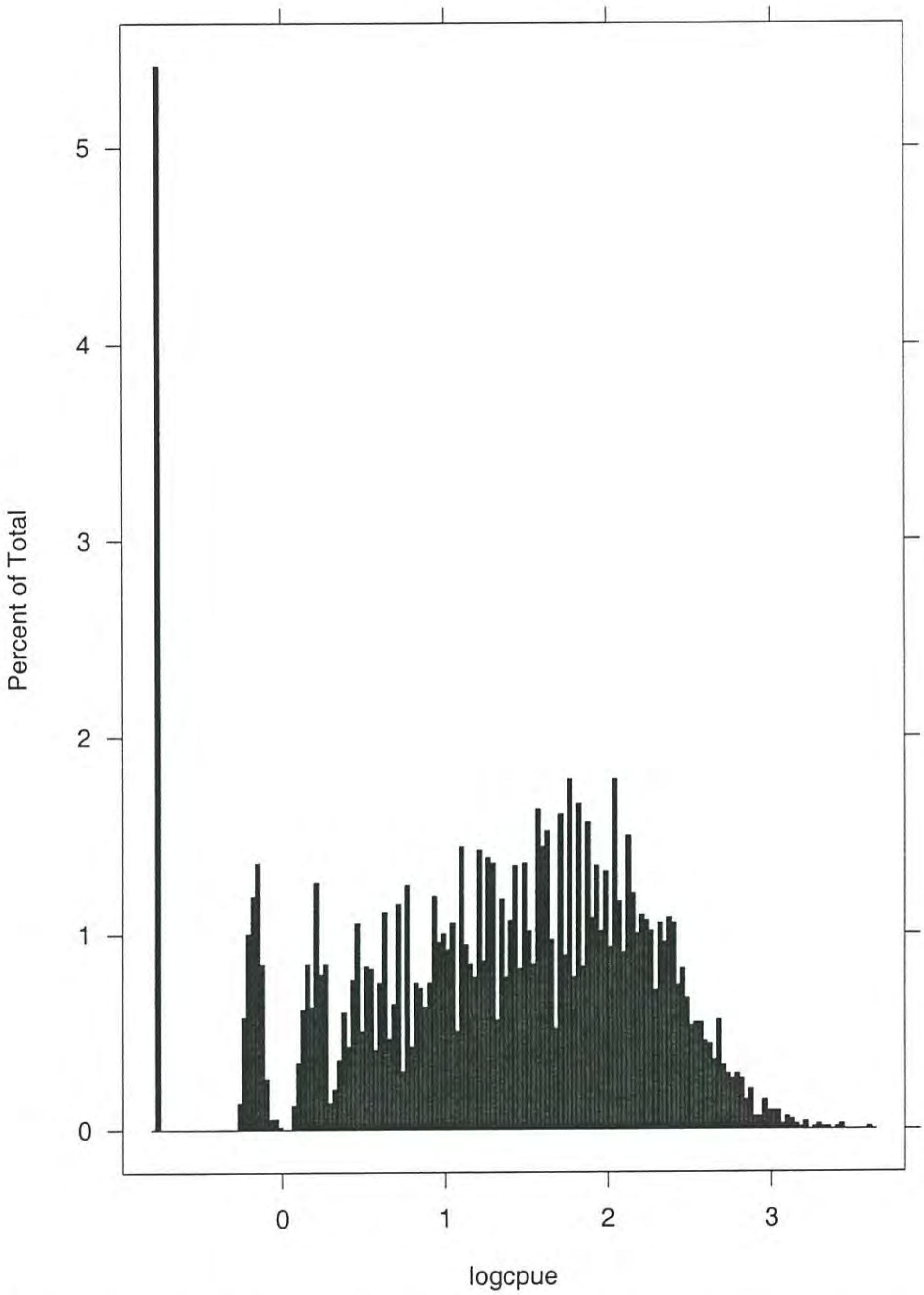

Figure 3: Histograms of $\log(CPUE + \delta)$ between 1980-1997 for the foreign fleet. Vertical axis is in probability(%)

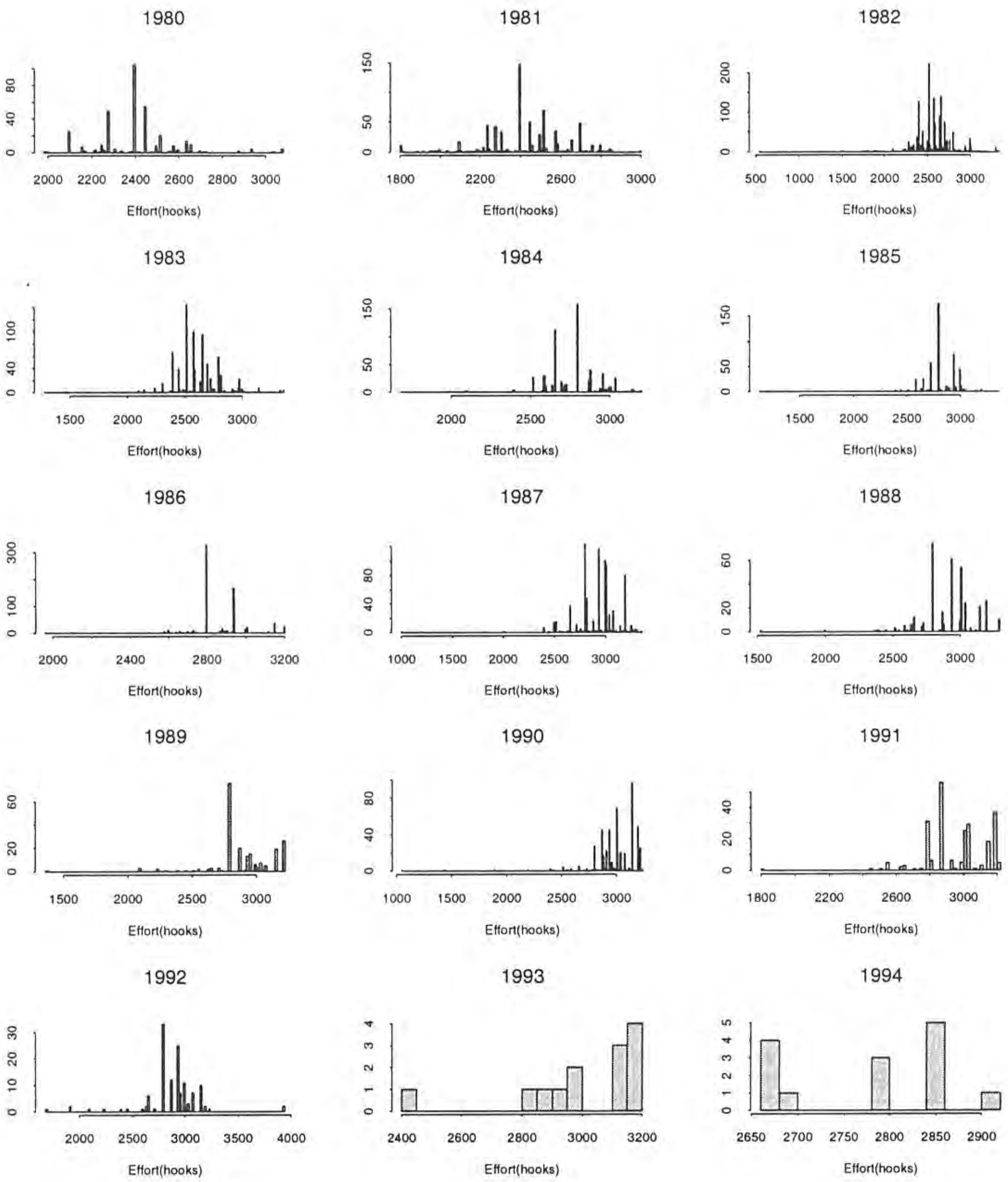

Figure 4a: Histograms of effort between 1980-1994 for the foreign fleet. Vertical axis is in counts.

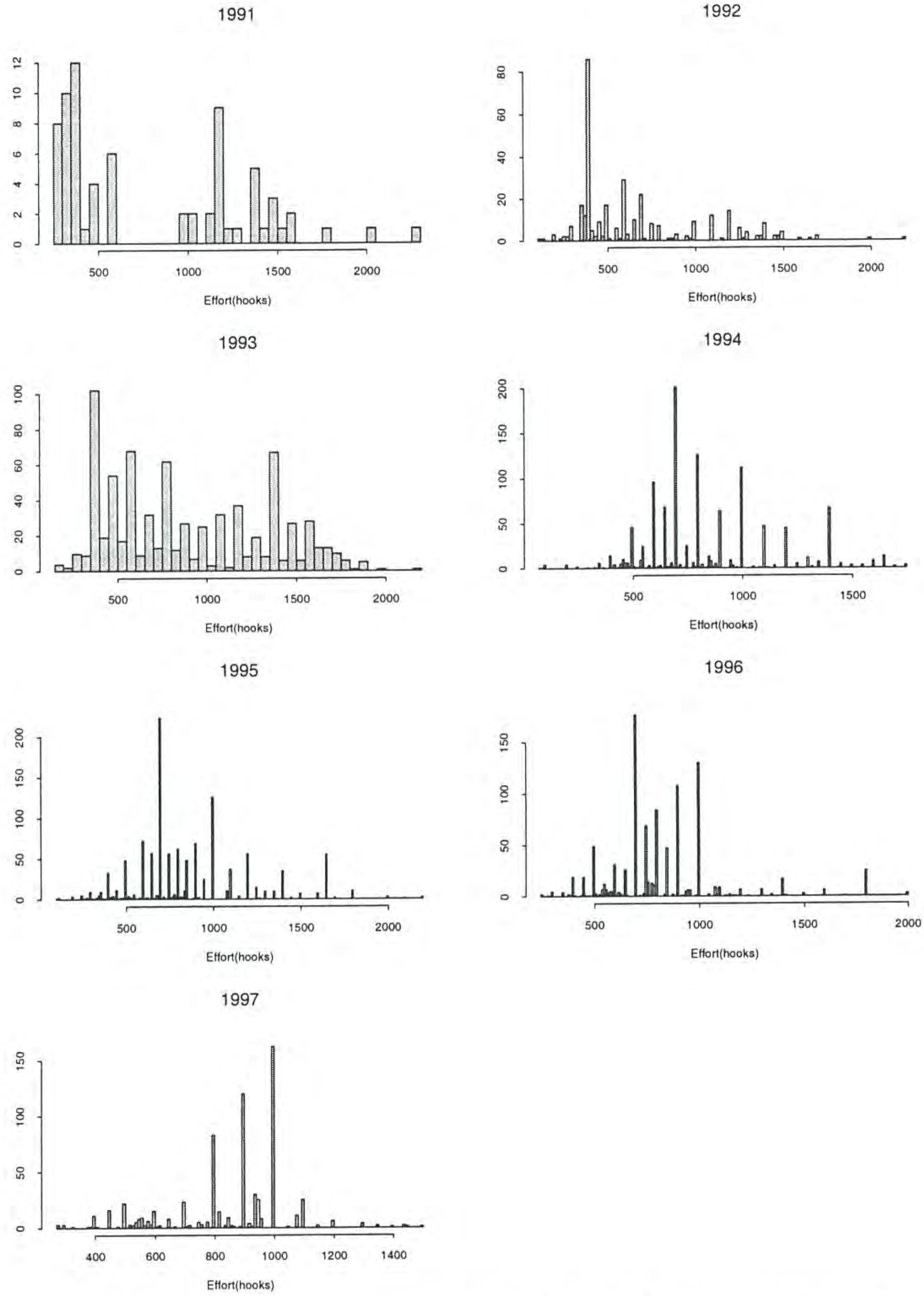

Figure 4b: Histograms of effort between 1991-1997 for the domestic fleet. Vertical axis is in counts.

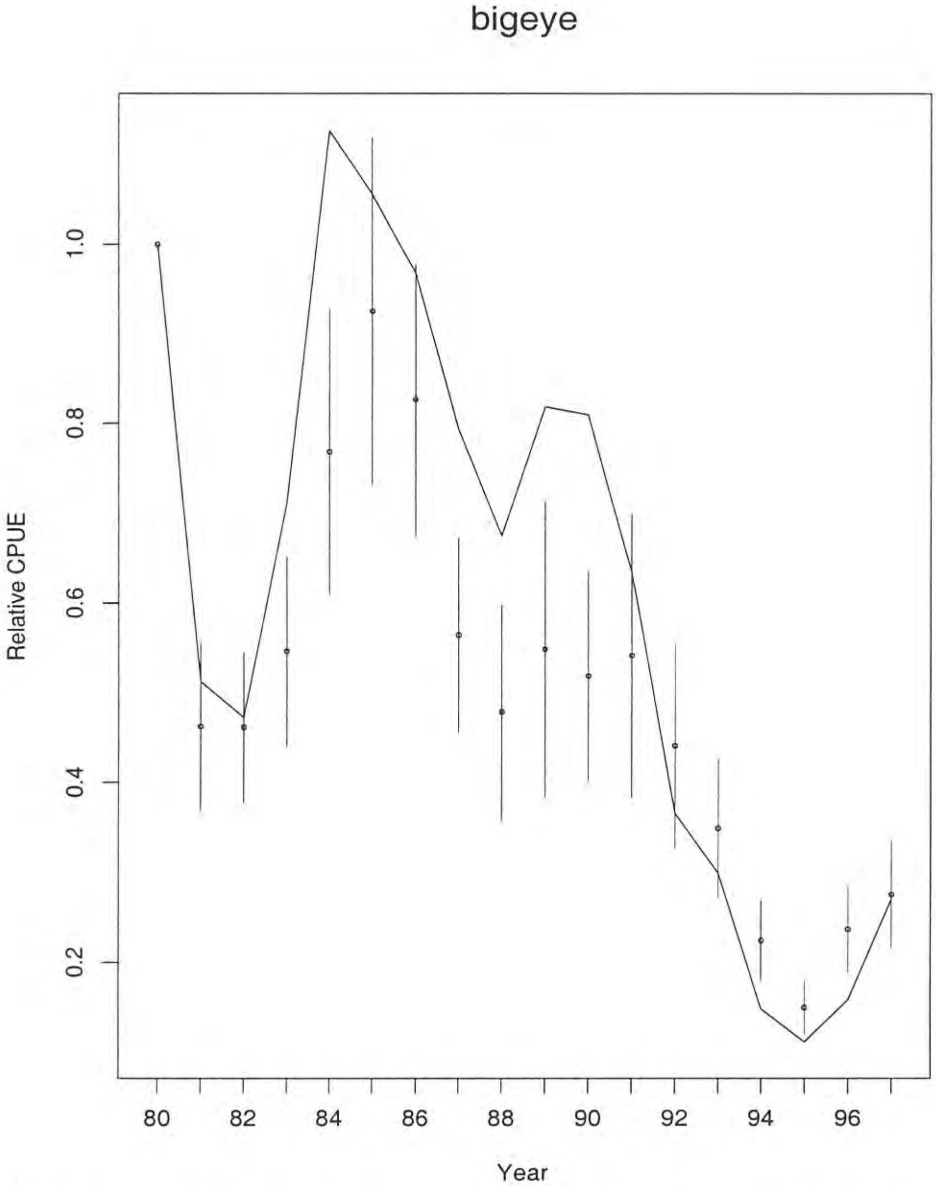

Figure 5a: Estimated year coefficients from the negative binomial model for bigeye. The line connects relative mean CPUE and bars represent 2σ errors computed from equation 3.2.

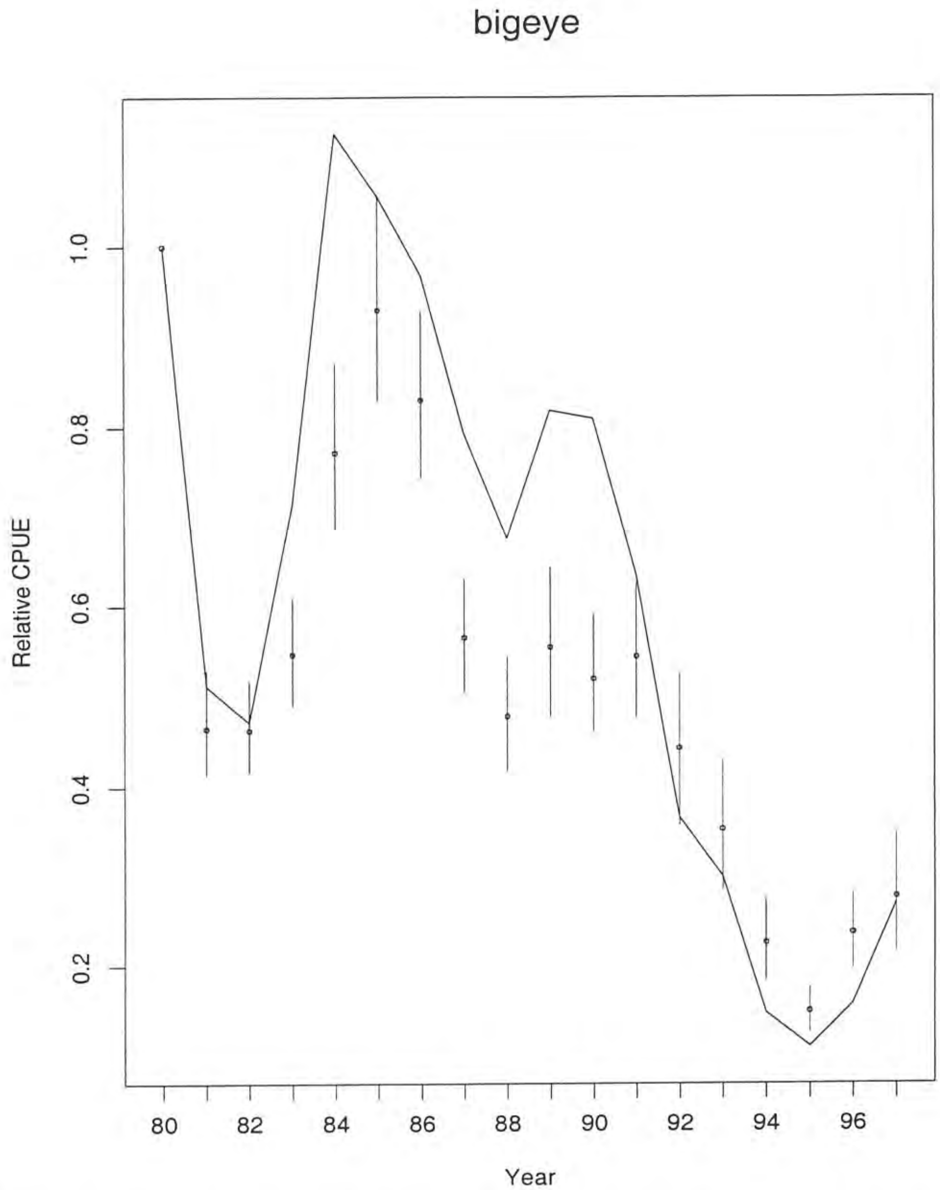

Figure 5b: Bootstrap mean year coefficients from the negative binomial model for bigeye. The line connects relative mean CPUE and bars represent 95% confidence intervals estimated using the bootstrap.

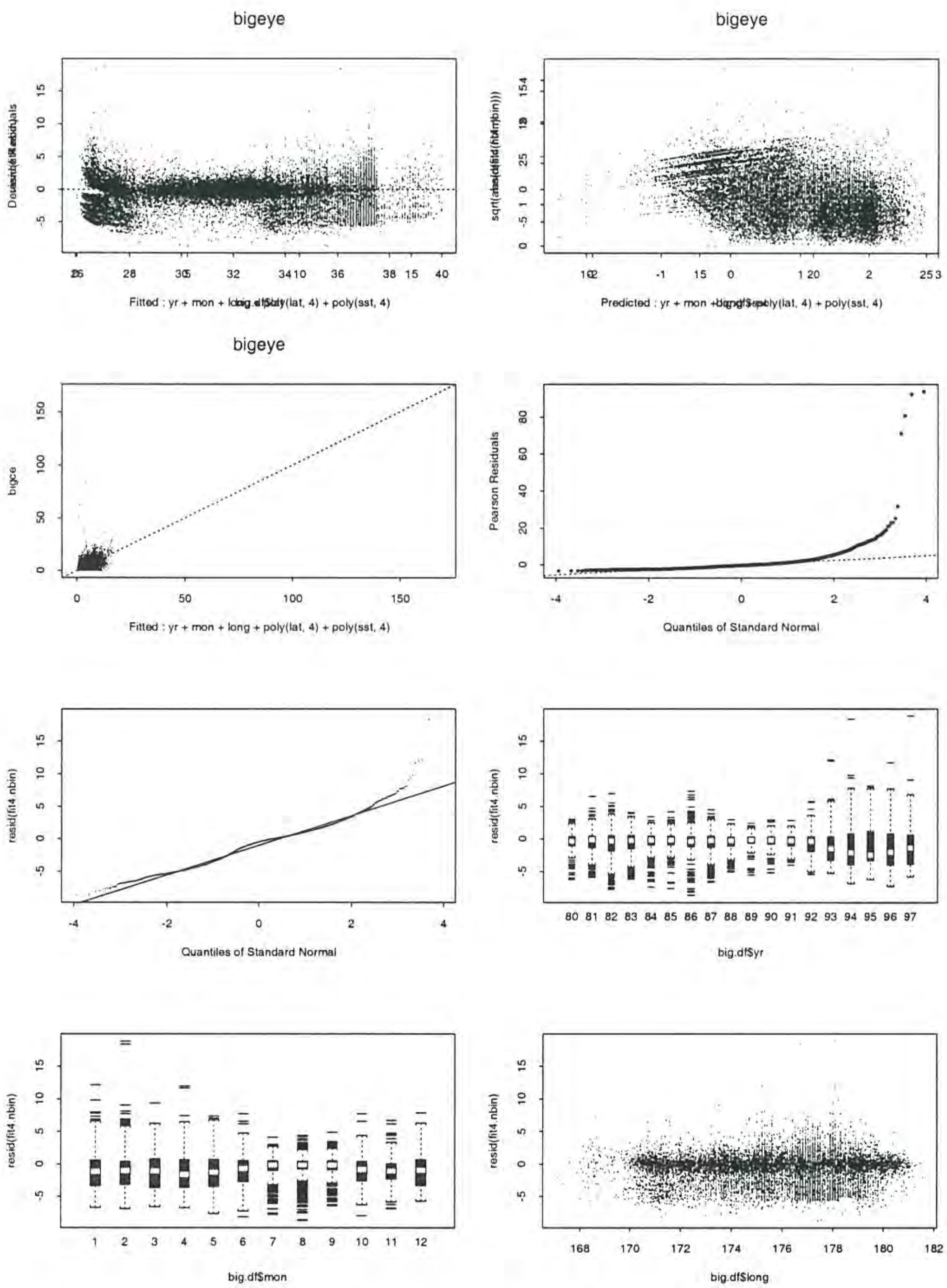

Figure 6 Residual plots for the negative binomial response model of bigeye CPUE data.
Call: fit.nbin_glm(bigce~yr+mon+long+poly(lat,4)+poly(sst,4),data=big.df,
family=negative.binomial(0.2),weights=wt^0.7)

APPENDIX 1: CPUE Data

Year	No. sets	hooks	catch	cpue	Zero sets	% zero sets	Year Index	S. Error
80	350	842	5201	6.2598	27	7.71	1	0
81	699	1699	5402	3.2069	57	8.15	0.4618	0.047
82	1445	3719	10963	2.9525	137	9.48	0.4611	0.0421
83	805	2108	9492	4.4611	66	8.2	0.5461	0.0533
84	574	1586	11266	7.0519	16	2.79	0.7684	0.0795
85	495	1391	9131	6.6115	7	1.41	0.9253	0.0968
86	705	2021	12261	6.0575	11	1.56	0.8265	0.0756
87	783	2291	11490	4.9667	36	4.6	0.5642	0.0545
88	350	1024	4275	4.2304	13	3.71	0.478	0.0599
89	212	614	3120	5.1248	4	1.89	0.5485	0.0824
90	477	1432	7273	5.0668	3	0.63	0.5184	0.0586
91	311	765	3213	3.9749	40	12.86	0.5413	0.0794
92	467	602	1628	2.2871	154	32.98	0.4405	0.0572
93	778	740	1362	1.8741	370	47.56	0.349	0.0384
94	1163	1003	975	0.9267	684	58.81	0.2243	0.0224
95	1224	1073	780	0.6918	775	63.32	0.1493	0.015
96	993	818	772	0.9885	593	59.72	0.2369	0.0244
97	682	582	885	1.691	365	53.52	0.2755	0.0296

APPENDIX 2: Model Residual Deviance

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
NULL			12512	112021		
yr	17	26409.91	12495	85611.1	235.5145	0.00E+00
mon	11	9321.07	12484	76290	128.4614	0.00E+00
long	1	421.89	12483	75868.1	63.9589	1.33E-15
poly(lat, 4)	4	462.85	12479	75405.2	17.5422	2.30E-14
poly(sst, 4)	4	511.76	12475	74893.5	19.3958	6.66E-16

APPENDIX 3. Summary of total longline effort and number caught when targeting bigeye, total tonnes caught includes bigeye bycatch by calendar year from TLCER data only.

Year	No. sets	Hooks (*1000)	No. caught	weight (t)
1980	350	842	5201	274.0
1981	699	1699	5402	526.5
1982	1445	3719	10963	702.9
1983	805	2108	9492	508.2
1984	574	1586	11266	610.0
1985	495	1391	9131	620.5
1986	705	2021	12261	758.9
1986/87	783	2291	11490	672.0/9
1987/88	350	1024	4275	277.0
1988/89	212	614	3120	185.3/0
1989/90	477	1432	7273	374.7
1990/91	311	765	3213	194.9
1991/92	467	602	1628	124.8/4
1992/93	778	740	1362	52.1/2
1993/94	1163	1003	975	89.4
1994/95	1224	1073	780	49.8
1995/96	993	818	772	79.3
1996/97	682	582	885	104.9

APPENDIX VIII: Models for southern bluefin tuna in the New Zealand EEZ

Models for Southern Bluefin Tuna in the New Zealand EEZ

K. Richardson, T. Murray, and H. Dean
NIWA, Greta Point
PO Box 14-901, Kilbirnie
Wellington, New Zealand

Abstract

Longline fishing effort has declined steadily within the EEZ coincident with the reduction in Japanese longline vessels taking up licences and a contraction of the fishing season by these vessels. No foreign licensed longliners have fished in the EEZ since 1995. Domestic longline effort, comprised of chartered Japanese vessels and New Zealand owned and operated vessels is of the order of 2-3 million hooks per year. Most SBT longline fishing takes place in June and July. The total catch in the EEZ has declined from 7609 tonnes since 1980 to 334 tonnes in 1997.

Estimating abundance indices for southern bluefin tuna from commercial catch and effort data has for some years been a routine part of stock assessment. Surprisingly, uncertainties remain about the statistical properties of these data and about the most appropriate models to use in the standardisation procedure.

We try to address this problem by considering longline catch-per-unit-effort as over-dispersed sample proportions where effort (total number of 'trials') is randomly selected from a known distribution. Variations in the effort (probability) distribution from year-to-year and between fleets complicate this picture but are accommodated reasonably well by a weighted negative binomial generalised linear model. Other ways of dealing these difficulties are suggested.

We also re-examine the relation between catch-per-unit-effort and abundance, concluding that a knowledge of, or assumptions about, the spatial distribution of the stock are necessary when estimating an abundance index. Initial results from work in progress at NIWA aimed at extracting spatial density information from the models used to standardise the catch and effort data are presented.

Nominal CPUE for both domestic owned and operated and for Japanese longliners indicate an increase in either 1994 (Japanese vessels) or 1995 (domestic vessels) that was preceded by an essentially flat CPUE trend. Nominal CPUE for both fleets have subsequently shown substantial declines. While the 1994/95 peaks could have been regarded as hopeful signs, they now appear to more likely reflect a short term fluctuation in local availability.

1. Introduction

Catch and effort data from commercial longline tuna fisheries pose special problems for analysis and modelling. The purpose of analysis is often to provide information about temporal trends in the abundance and distribution of the stock which will be of use in the management of the fishery.

Since Allen & Punsley (1984), multiple regression or, more recently, generalised linear models (GLMs) have often been used to try and account for systematic changes in catchability, fishing power etc., on the assumption that the remaining systematic variability in the CPUE data is related to abundance.

Despite the popularity of this approach (see e.g., Richardson *et al* 1997 and references therein), there have been several important issues that have either not received much attention, or have not been satisfactorily resolved. One such issue is the statistical properties of the random component of CPUE data. The second concerns the spatial aspects of the systematic component. In the latter case, the importance of including the spatial distribution of the stock in calculations of a CPUE index of abundance may have been under-estimated.

We hope to outline work in progress that suggests that progress on both these problems can be made using standard GLM methods.

2. Method

Catch and effort data for target and by-catch species (given as numbers of fish, and numbers of hooks), longline set position, date, start and finish times, sea surface temperature, cloud cover, vessel specifications and other fisheries data were obtained from Ministry of Fisheries for the period 1980-1997. These data were checked and groomed by NIWA

Moon phase calculations were based on algorithms given by Duffet-Smith (1990). Fishing areas chosen for the analysis are those identified by Bradford *et al* (1995), and are shown in Figure 1.

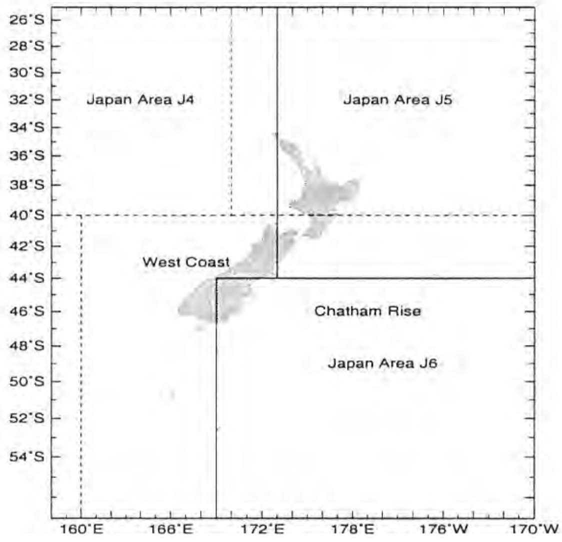

Figure 1.1: Map of New Zealand showing the three regions (solid lines) used in this document - East Cape, West Coast and Chatham Rise. Also shown are the Japanese statistical areas 4, 5, and 6 (dotted lines)

A. CPUE Statistical Models

1. Models for the Random Component

A common approach to deciding which model of this component is best suited to CPUE data has often been empirical. In the context of a GLM, this may involve trying the distributional forms that are available within some statistical package. More particularly, since a GLM model relies only on the lower moments (mean and variance) of a distribution (McCullagh & Nelder, 1989), this reduces to searching for a mean-variance relationship that performs "best" (e.g., with respect to the behaviour of the residuals from the fitting process).

A general consensus has emerged in the analysis of SBT catch and effort data that log-normal errors perform well (e.g., CCSBT Workshop on VPA and CPUE Modelling, 1996). However, zero catches present a difficulty for the log-normal model, which is usually resolved by adding a constant (denoted δ here) to the CPUE data before fitting the model. The arbitrary constant can, if required, be removed from the constant term computed using the model.

Other approaches have been proposed. Vignaux 1994 and later Bradford *et al* 1995 suggest combining a binomial model (of the probability of zero catch) with a log-normal model of positive CPUE.

Most of these approaches suffer from being somewhat ad-hoc, and a more detailed analysis of the properties of longline CPUE data is overdue. While it is probably too difficult to derive the distribution itself, there is some hope that more useful models might be suggested by such an analysis. We begin by studying the CPUE data itself.

Figure 2.1 presents a histogram of $\log(\text{CPUE} + \delta)$ data from the East Coast region for the foreign fleet in the years 1980-1997 (the constant δ is chosen to be one-tenth of the smallest positive CPUE value). It is immediately apparent that the distribution of these data has identifiable peaks at several distinct values of CPUE rather than just one "point mass at zero" as has been suggested (e.g., Chesson & O'Brien, 1996). Figure 2.2 shows the histograms for the same data separately for each year. While there are strong temporal variations, the presence of distinct peaks at "small" CPUE values is a characteristic of all but some of the more recent data (not surprising because of its sparseness).

The reason for this property is not hard to understand, as Figure 2.3 makes clear. The distribution of $\log(\text{CPUE} + \delta)$ for the foreign fleet in 1982 is shown separately for $\text{catch} = 1,2,3,\ldots,10$. Foreign fleet data for this year were used because they comprise a reasonably large and homogeneous set. There is a separate peak for each unit of catch until the peaks coalesce at larger values. Furthermore, Figure 2.3 suggests that at a given value of catch, different levels of effort contribute to the variability in CPUE. A reasonable inference is that catch is a counting process, and effort is a random variable so that CPUE can be viewed as proportions (of successes) where the total of successes and failures (i.e., effort) can vary.

The distribution of CPUE for fixed effort is likely to have much simpler distributional properties. This is confirmed by Figure 2.4, which is a histogram of $\log(\text{CPUE} + \delta)$ for an effort of 3000 hooks in all years (1980 and 1997). It should be noted that the distribution of effort changes significantly from year-to-year, particularly in recent years (see Figure 2.5a for the foreign fleet and Figure 2.5b for the domestic fleet). While this complicates the treatment of CPUE, the effort distribution is known in any given year, and this prior knowledge will prove useful in what follows.

To make further progress, it is necessary to consider the longline fishing operation in more detail. If the probability of catching a fish on any hook was constant and independent of catching a fish on other hooks, then CPUE could be regarded as samples from a binomial population. A binomial GLM would probably be a reasonable model for the random component of CPUE data in a given year provided that SBT were distributed uniformly across a given region although the year-to-year variation in effort might still cause some difficulty. In fact, since the probability of catching an SBT on a given hook has always been small, a Poisson model might also be useful (see Richardson *et al*, 1997).

However, the distribution of SBT is highly non-uniform, and fishers have good but not perfect knowledge of where to find them. Hence, over-dispersion (relative to binomial or Poisson models) is to be expected. In an effort to shed some light on the low order moments of CPUE variability, Figures 2.6a and 2.6b explore possible mean-variance relations in the data. In both cases, combined CPUE means and variances (i.e., foreign and domestic) have been computed for each year:month stratum in the East Coast region at a fixed effort of 3000 hooks. Figure 2.6a suggests a power-law relation, whereas Figure 2.6b is more in keeping with the relation expected for a negative binomial distribution

$$\sigma^2 \propto \mu(1+\frac{\mu}{\theta}) \qquad (1.1)$$

where σ^2 is the variance, μ is the mean and θ is the so-called shape parameter. The correlation, however, is not as strong in Figure 2.6b ($R^2 = 0.54$) as it is in Figure 2.6a ($R^2 = 0.8?$). Both these forms can be accommodated within a GLM, though a power-law model must appeal to the concept of quasi-likelihood (McCullagh & Nelder, 1989). Negative binomial models, on the other hand, are of exponential form, and have often been used with over-dispersed Poisson data (Venables and Ripley, 1996).

As noted previously, the simplest distributional properties for CPUE can be expected at a fixed effort and within one year. Figure 2.7 presents quantile-quantile (qq) plots for Poisson, power-law, and negative binomial models in the East Coast region for 1982 foreign CPUE data with 3000 hooks. These results are similar to other year, area, and effort strata, and suggest that the power-law and negative binomial GLMs produce moderately normal residuals for these data.

We note that the negative binomial model used was that given by Venables & Ripley, 1996 so that the shape parameter had to be estimated by trial-and-error. These authors have also provided an Splus function that allows maximum likelihood estimation of this parameter, but this has not been used in the work reported here.

The acceptability of the negative binomial model provides some support for the interpretation of CPUE as over-dispersed counts, at least for fixed effort within one year To make further progress it is also necessary to allow effort to vary in the CPUE sample. Figure 2.8a is a qq plot for a negative binomial GLM of 1982 foreign CPUE data. Figure 2.8b provides similar information for a power-law GLM of the same data. Parameters for both these models are chosen empirically by examination of residual plots. With respect to the normality of the model residuals, both appear to be acceptable.

The main point of fitting a GLM to longline CPUE data is to estimate temporal changes in an abundance index 'corrected' for variations in catchability and, perhaps, vessel-related effects. Often, this is done by including a predictor variable for year (and, perhaps, month) but according to the picture of CPUE developed above, this introduces a further complication since the distribution of effort changes noticeably from year-to-year (see Figure 2.5).

Figure 2.9 is a qq plot for residuals from negative binomial and power-law GLMs of the East Coast foreign fleet CPUE data from 1980-1997. Parameters for the distributions are chosen for normality of residuals. Compared to the fits for a single year's data, the distributional assumptions may not be quite as good. There appears to be a longer tail(s) than for a normal distribution, though the problem is a little less severe for the negative binomial model.

The distribution of effort in each year is, however, known and this knowledge can be used to advantage. Recall the method used in 'S' to fit binomial data. Counts are converted (if required) to proportions, and total counts (successes + failures) are passed as weights to the fitting function. Since the difficulty here is yearly variation in effort, we compute the probability of a given effort in a given year, and use this information to compute appropriate weights. In fact, a power function of effort probabilities provides enough control to (approximately) normalise model residuals.

Figure 2.10a and Appendix 2 provide an example of using these ideas (for the foreign and domestic fleet in the East Coast region) about the nature of the random component of CPUE data, and more examples are given in the following section for the other regions. The shape parameter and weight function have been chosen by trial and error in the usual way. Once this has been done, there appear to be no serious violations of the distributional assumption, so there can be reasonable confidence in the standard asymptotic tests of residual deviance. It was not possible to optimise residual plots in the same way for the power-law model.

The results obtained so far suggest that it may be profitable to view CPUE data as proportions computed from over-dispersed counts, and to derive weights from known effort data to reduce problems caused by changes in this distribution with time. This approach is used in the analysis that follows.

3. Application to the New Zealand EEZ

We now briefly describe the construction of main effects GLM models as they have been applied to CPUE data in the New Zealand EEZ.

A. Model Parameters and Predictor Variables

In the first instance, the model for each area given by Richardson *et al*, 1997 was used to find optimum values (see above) of the shape parameter θ and the index of the weight power function. The S function `step` was then used to select predictor terms, and these were tested with the usual F statistic at a significance level of 10^{-9}.

Predictor variables used included:

1. Factors
    - *year*
    - *month:* February to August
    - *fleet:* Foreign (Japanese or charter), Domestic (NZ owned and operated)
2. Covariates
    - *moon phase*
    - *sea surface temperature*
    - *latitude*

- *longitude*

Covariates were Hermite polynomials up to order 3. The order of the polynomial was chosen by step.

B. Estimated Model Coefficients

Figures 3.1 to 3.3 contain graphs of fitted year factor levels and mean (unstandardised) CPUE in each of the three fishing areas for each fitted model. Tables of these and other data are given in Appendix 1.

The final accepted model is given (in S notation) in Appendix 2. The standard error for the year coefficient on the scale of the response variable, $\exp(\hat{y})$, is calculated as

$$\mathrm{var}\left[(\exp(\hat{y})\right] = \exp(2 * \hat{y}) e^{v} (e^{v} - 1) \qquad (3.1)$$

with v the appropriate diagonal element of the covariance matrix, and $\hat{y}$ the value of the year linear predictor estimated during the fitting procedure. This equation assumes the residuals are normally distributed which may be questionable for the negative binomial models used here. Bootstrap confidence intervals would be of considerable interest, but have not been computed for these results.

The predictor variables for year, month, moon phase, latitude and longitude, were always significant. Sea surface temperature was significant in the Chatham Rise.

The year effect was not significant for the domestic fleet data when modelled separately, and , and the fleet factor in a combined model was not significant in any region.

C. Residuals

There is no strong evidence in any of the usual residual plots of inadequacy in the negative binomial models (see Figure 2.10). Tables of deviance residuals are given in Appendix 2.

D. Discussion and Conclusions

1. Year coefficients

a) East Cape

Between 1980 and 1996, there are only marginal differences between the estimated coefficients and the nominal (mean) CPUE values (see Figure 3.1). There is an apparent increase in both CPUE and fitted coefficient in 1997, but this results from 3 very high CPUE sets. A similar short-term event was observed in 1990.

b) West Coast

There appear to be some differences between mean yearly CPUE values, and estimated year coefficients (Figure 3.1). However, there was a sharp reduction in effort after 1993 particularly in 1994, 1996, and 1997 (see Appendix 1) and this is reflected in the increase in the size of the error bars over that period. Since the estimated errors almost certainly understate the actual uncertainty (and we have not yet produced bootstrapped confidence intervals), it is difficult to be certain about the status of and trends in the fishery for the West Coast region. It is interesting to note that although the glm year coefficients show a similar trend to the mean CPUE estimates, the magnitude of fluctuations is smaller. This behaviour is not seen in the other two regions.

c) Chatham Rise

Figure 3.1 shows the results when years 1992-1996 are combined (since there was very little fishing in this period). The comments made above for the East Coast region, particularly the 1997 result, are relevant here also, although the increase in 1997 does not appear to have come from only a small number of sets.

2. Statistical Models

The negative binomial sampling model appears to have performed quite well for these data, and work is planned to see whether this is true more generally. We note that dealing with overdispersion is an area of current research in the statistical literature. For example, Fitzmaurice, 1997 notes that overdispersion is quite common in exponential family response models, and suggests a modification to the GLM framework, based on a double exponential family formulation, to account for it. He argues that this relatively straightforward adjustment to the GLM framework allows predictor variables for both mean and dispersion, while retaining the relative simplicity of the GLM approach. Results reported here suggest that the ability to allow year and area effects in dispersion may be a useful approach and further work in this area is planned.

4. Spatial Effects in CPUE Models

A. Introduction

Richardson *et al*, 1997 noted that the interpretation of year effects from CPUE models is complicated by the highly non-uniform distribution of effort in commercial CPUE data.

Many others (e.g., Hilborn & Walters, 1992) have highlighted problems that can arise from assuming that CPUE is proportional to abundance. Some of these difficulties appear to arise from the way in which a more general abundance (i.e., relevant to a much larger region) is computed from fine-scale CPUE data We now show that it is still useful to assume that CPUE is proportional to a local density (or abundance) of fish over the time of the fishing operation.

For example, suppose $U(\mathbf{r},t)$ is the CPUE for a longline 'at' position **r** and time *t*, and ΔA is the maximum area encompassing the longline over which SBT can detect the bait. Then $U_{\Delta A}(\mathbf{r},t)$ is the average probability of catching an SBT in the region during a fishing operation and it is reasonable to assume that

$$E\left[U_{\Delta A}(\mathbf{r},t)\right] \approx Q(\mathbf{r},v,t)\rho_{\Delta A}(\mathbf{r},t)\Delta A \tag{4.1}$$

or

$$E\left[U_{\Delta A}(\mathbf{r},t)\right] \approx Q(\mathbf{r},v,t)N_{\Delta A}(\mathbf{r},t), \tag{4.2}$$

where $\rho_{\Delta A}$ ($N_{\Delta A}$) is the local mean density (local abundance) of SBT, $Q(\mathbf{r},v,t)$ is a local catchability coefficient for vessel v, and $E[\ ]$ means expected value. More generally, $\rho_{\Delta A}$ would be the local mean abundance of fish that can detect and access the bait, but in the present case it can probably be assumed that if an SBT can detect the bait, it can also access it. These models remain plausible whether the search is 100% efficient or whether local depletion take place, since the next fishing operation would find a reduced local abundance (density), perhaps even zero. In principle, Q could vary from vessel to vessel, and modelling would try to account for such variations, but there is no evidence that this is necessary for SBT longliners so the vessel argument v can be dropped and we suppose $Q(\mathbf{r},v,t)=q(\mathbf{r},t)$.

Usually, several fishing operations take place over a larger area *A* (e.g., the East Coast region of Figure 2.1) and time interval ΔT (e.g., a year). It would be prudent to restrict estimation of the spatial distribution of SBT in a given time interval to the region $A_{samp} \subset A$ which is 'well sampled', since estimation avoids extrapolation outside the sampled area. The highly non-uniform effort distribution of commercial fishing operations makes interpolation difficult enough!

It can be noted in passing, that conclusions about abundances within the larger area A are unlikely to be reliable without prior knowledge of the spatial distribution. The problem of what to do about unfished areas (i.e., outside A_{samp} but within *A*), so contentious in assessment meetings, is actually inherent in CPUE data itself, and needs to be accounted for when deriving CPUE abundance indices from fine-scale data.

Apart from restricting estimation to the smallest possible box covering fishing operations in one year (and excluding land), we have not attempted to define A_{samp}, since we are more interested at this stage in explaining the general idea behind current work in progress. The problems caused by the crudity of this assumption will become apparent later.

B. Estimating SBT spatial distribution functions

The underlying model, as given above, is

$$E[U_{\Delta A}(\mathbf{r},t)] = q(\mathbf{r},t)\Delta A \rho_{\Delta A}(\mathbf{r},t). \tag{4.3}$$

As in Richardson *et al*, 1997 we assume that the functions $q(), \rho()$ are separable, and that the large-scale time dependency in the density can be approximated by a step function at appropriate time scales (*year* and *month* here) so that

$$\rho_{\Delta A}(\mathbf{r},t) \approx d_{y*m} \Delta A f(\mathbf{r}| y,m). \tag{4.4}$$

In this equation, d_{y*m} is a density amplitude step function that is constant for year y and month m, $f(\mathbf{r}| y,m)$ is a spatial distribution function that depends only on position **r** for year y and month m, and ΔA is as above.

The catchability q can depend on position and time explicitly (for instance by increasing as technology improves over time, or via other factors), and implicitly through a variety of quantities e.g., environmental effects such as sea surface temperature (*T*), moon phase (Φ_M) and so on. A reasonably general form that has only implicit position dependence might be

$$q(\mathbf{r},t) \approx q'_y q_1(T) q_2(\Phi_M)\ldots \tag{4.5}$$

so that the final model for CPUE becomes

$$E[U_{\Delta A}(\mathbf{r},t)] = [q_1(T)q_2(\Phi_M)\ldots]\Delta A \bullet [q'_y d_{y*m}] f(\mathbf{r}| y,m). \tag{4.6}$$

Explicit time dependence exists only through the product in the second square brackets, and explicit spatial dependence only via the spatial distribution function *f*.

Equation 4.6 has a form that is amenable to a GLM with a logarithmic link function (since the model is multiplicative) i.e., it may be possible to estimate the various terms. More general functional forms could be assumed, but these would need the additional flexibility provided by generalised additive, or fully non-linear models. Such an extension would probably be useful, but the linear model is sufficient here.

For simplicity, it is also assumed that the catchability has no explicit time dependence, ($q'_y = 1$, for all years *y*), but it should be borne in mind that changes in catchability over the period of the fishery will be contained within the year coefficients estimated by the GLM. A similar comment applies if catchability has an explicit positional dependence. It should also be noted that commercial fishing operations impose a sampling 'window' on the spatial distribution function. As noted above, extrapolation beyond that window is likely to be misleading.

C. Spatial Distribution of CPUE for Main Effects Models

It is useful at this point to note that equation 4.6 also underlies the main effects models discussed in Section 3, but in the simpler form

$$E\left(U_{\Delta A}(\mathbf{r},t)\right)=\left[q_1(T)q_2(\Phi_M)\ldots\right]\Delta A \bullet \left[q'_y d_{y+m}\right]f(\mathbf{r}) \qquad (4.7)$$

i.e., the spatial distribution function f is the same for all years (and months). This is probably not a very good assumption (see below), but has two important advantages. Firstly, it significantly reduces the number of parameters estimated by the model, and secondly, the ratio of year coefficients is an estimate of the ratio of densities (or abundances) within the sampled area. This is not the case with the more general model (equation 4.6), and abundance indices must be derived by integrating over the spatial function.

For comparison with later work, Figure 4.1 displays the spatial distribution function $\hat{f}(\mathbf{r})$ estimated using equation 4.7 in the Chatham Rise sub-region containing no land. Figure 4.2 shows yearly contour plots of $\log(\text{CPUE} + \delta)$ for the same area, and shows quite clearly that the CPUE sampling 'window' has changed quite significantly over time. The main effects model captures little of this complexity, and in later years provides predictions that appear to be unlikely (e.g., compare the fitted spatial and actual spatial CPUE distribution in 1997 from figures 4.1b and 4.2b). Most of the data is contained in the early years of the fishery, and the spatial fit is probably more representative of an average over those years.

D. Temporal Effects in the Spatial Distribution

By including appropriate *year:latitude* and *year:longitude* interaction terms in the predictor function, it is possible to estimate changes in the SBT and effort distribution at yearly intervals. Figure 4.3 presents the fitted spatial terms for the Chatham Rise sub-region which excludes land. Table 2.4 in Appendix 2 provides the deviance residuals from the model, and it can be seen that the main effects and interaction terms for longitude and latitude are all significant. There is little data in the years 1992-1996, so these years have been combined.

Comparison with the CPUE plots in Figure 4.2 suggests that some of the broad features of fishing operations are captured by the estimated spatial density functions. The behaviour of these functions at the edges of the region in some years is questionable (see 1989, for example) and highlights the unsuitability of polynomial fitting functions as well as the problems caused by the absence of data (and the danger of extrapolating densities) outside the sampled area. Figure 4.4 presents one dimensional plots together with estimated standard errors.

Clearly there is more to do before firm conclusions can be drawn about this approach, but several preliminary points and indications of future directions can be made.

1. The results are encouraging given that the functional form (polynomials) chosen to fit the spatial effects are unlikely to be suitable. We know, for example, that any spatial distribution has to be integrable over a restricted region, and a polynomial doesn't capture this behaviour except in very localised areas. The tendency for the fitted polynomial to become very large at a boundary of the region in specific years is probably symptomatic of this. More acceptable performance may perhaps be achieved using generalised additive, or other non-linear, models since the restriction to fitting polynomial predictor functions is relaxed.
2. Including temporal effects in spatial terms captures some of the variability in fishing from year-to-year, though at the cost of having to estimate more coefficients and of having to integrate over the spatial effects to extract abundance indices. Whether this adds anything to current procedures remains an open question at this stage
3. We have made no attempt to limit the estimated spatial functions to an adequately sampled spatial 'window'. Consequently, the spatial distributions presented above are likely to be quite unreliable at points outside such a window. In the absence of data from a well-designed survey, it is scientifically justifiable to assign zero abundance to areas outside, and the question of how to define an appropriate window in a given area needs further consideration.
4. Equation 4.6 includes a term ΔA for the local area 'swept' by the longline, though no attempt was made to fit such a term. However, it is plausible that such a quantity would depend on effort (perhaps up to a polynomial of order 3) and it is intriguing that both Richardson *et al*, 1997 and this work find that such an effort term in the linear predictor is often significant (e.g., see Table 2.4 in Appendix 2). Further consideration of this effect is required.

5. Summary of CPUE Models

Results from Sections 2 and 3 suggest that an effort-weighted negative binomial response model is suitable for modelling set-by-set CPUE data in the New Zealand EEZ. The model arises from the authors' contention that CPUE can be usefully viewed as over-dispersed counts or proportions (i.e., a binary response variable) where effort, equivalent to the total number of 'trials' in a given set, is also a random variable but with a known distribution in any one year.

Weighting each set with a power function of the probability of effort expended in that year provides a means of compensating for yearly changes in the effort distribution, and possibly between fleets as well. There may be other, more powerful ways of coping with these aspects of CPUE behaviour. The Fitzmaurice (1997) extensions to the GLM framework, for example, may retain the advantages of efficiency and ease of interpretation provided by the GLM suggested here compared with other approaches such as random-effects models.

Separate main effects models for each of the three regions in the New Zealand EEZ provide no evidence of any improvement in the SBT CPUE abundance index. A few very high CPUE produce an apparent increase in the 1997 fitted year effect (as well as in the average CPUE for that year), but the significance of the increase is small (because effort has been low in all years since 1992 in both regions).

Section 4 demonstrates that the relationship between CPUE and density (abundance) can be modelled as a local effect, and the spatial distribution of the stock should be taken into account when deriving an abundance index. Extracting the estimated spatial terms from a GLM fit with *year:position* interaction terms may provide an insight into how the spatial distribution of fish (and/or effort) changes with time.

6. Fisheries Indicators

Total Catch and Effort

Total catch in the EEZ has steadily declined, as has total longline effort, from a peak of 7609 tonnes in 1980 to 334 t in 1997. Much of the decline is due to declines in Japanese longline fishing (see Appendix 3). No foreign licensed fishing has been undertaken since 1985 and total longline effort in the EEZ is directed at New Zealand's domestic catch limit (420 tonnes) by domestic owned and operated and by chartered Japanese longline vessels. Domestic longline effort for SBT is of the order of 2-3 million hooks annually.

Size Composition of the Catch

Since there has been no foreign licensed longline fishing in the EEZ since 1995, the trend in size composition is drawn from data collected in the domestic fishery (see Figure 4.5). It is clear from this figure that SBT smaller than 20 kg processed weight present in the very early 1980s were absent from the EEZ catches until 1989. The reappearance of small SBT in the New Zealand area, particularly in 1990, has been variable through the early-mid 1990s. However, in 1996 and 1997 small SBT have been a predominate component of the fishery and in the last two years SBT larger than 80 kg have been virtually absent.

CPUE

Nominal CPUE for domestic owned and operated longline vessels and for Japanese longline vessels (foreign licensed and chartered) are shown in Appendix 4. Fleets are combined in this way because of gear similarities and to maintain confidentiality for specific companies, as is required by the Ministry of Fisheries. Nominal CPUE for domestic owned and operated longliners is 2-3 times lower than for Japanese longliners. Domestic longlining began in 1991 and reached a peak of 1.405 SBT per 1000 hooks in 1995. Nominal CPUE for this fleet has been substantially lower in each subsequent year. Japanese longliners have been characterised by a flat CPUE trend throughout most of the 1980s through to 1994 when CPUE reached 4.115 SBT per 1000 hooks. Those Japanese longliners operating in the EEZ in 1995 and 1997 have had substantially lower CPUEs (about 2.6 SBT per 1000 hooks). Foreign licensed vessels left the New Zealand EEZ in 1995 and have not returned, however, chartered longliners absent in 1996 returned in 1997 but realised CPUEs roughly equivalent to those in 1995.

Standardised CPUE trends by major fishing areas are shown in figure 3.1. As has been discussed previously, interpretation of standardised CPUE varies considerably with area fished within the EEZ. In part because the amount of fishing in each areas has changed over time, for instance the Chatham area, important in the early 1980s is now fished very little and 80-99% of all fishing since 1991 has taken place in the West Coast and East Cape fishing areas. In general the standardised CPUE trends for the three areas closely resembles the nominal CPUE trend. This shows a regular decline in relative abundance between 1980 and 1996 to less than 20% in both the East Cape and Chatham Rise fishing areas followed by a dramatic increase in1997 to 30-40% of 1980 levels. The standardised trend for the West Coast fishing area, however, differs markedly from that of the nominal trend after 1988. Standardised CPUEs, unlike the other two areas, are substantially higher than nominal values but both show a marked decline in relative abundance from 1994. In each area, the relative abundance in 1997 is about that of the mid-late 1980s.

Acknowledgements
The research reported here was supported by the New Zealand Ministry of Fisheries under contract through NIWA Project TUN9701. The authors gratefully acknowledge this support.

7. References

Allen, R. L. & Punsley, R. G. (1984) Catch Rates as Indices of Abundance of Yellowfin Tuna (*Thunnus albacares*) in the Eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm. Bull., **18** (4), p. 30

Bradford, E., Dean, H., Murray, T. (1995) CPUE Trends in the Longline Fishery for Southern Bluefin Tuna (*Thunnus maccoyii*) in the New Zealand EEZ, 1980-1994. SBFWS/95/3

Chesson, J. & O'Brien, C., (1996) An Examination of Generalised Linear Models Applied to Fisheries Catch Rate Data, Bureau of Resource Sciences, Canberra

Chambers, J. M. & Hastie, T. J. (1992) *Statistical Models in S* Wadsworth & Brooks/Cole, Pacific Grove, California

Report on the CCSBT Workshop on VPA and CPUE Modelling (1996), 4-15 March, Hobart, Tasmania

Duffet-Smith, P. (1990) *Astronomy with your PC* Cambridge University Press, Cambridge

McCullagh, P. & Nelder, J.A. (1989) *Generalised Linear Models*

Richardson, K. M., Murray, T., Dean, H., (1997) Generalised Linear Models for Southern Bluefin Tuna in the New Zealand EEZ. CCSBT-SC/9707/9

Venables, W. N. & Ripley, B. D. (1996) *Modern Applied Statistics with S-Plus* Springer-Verlag, New York

Vignaux, M. (1994) CPUE Analysis of East Coast South Island and Cook Straight Spawning Hoki Fisheries. New Zealand Fisheries Assessment research Document 94/11

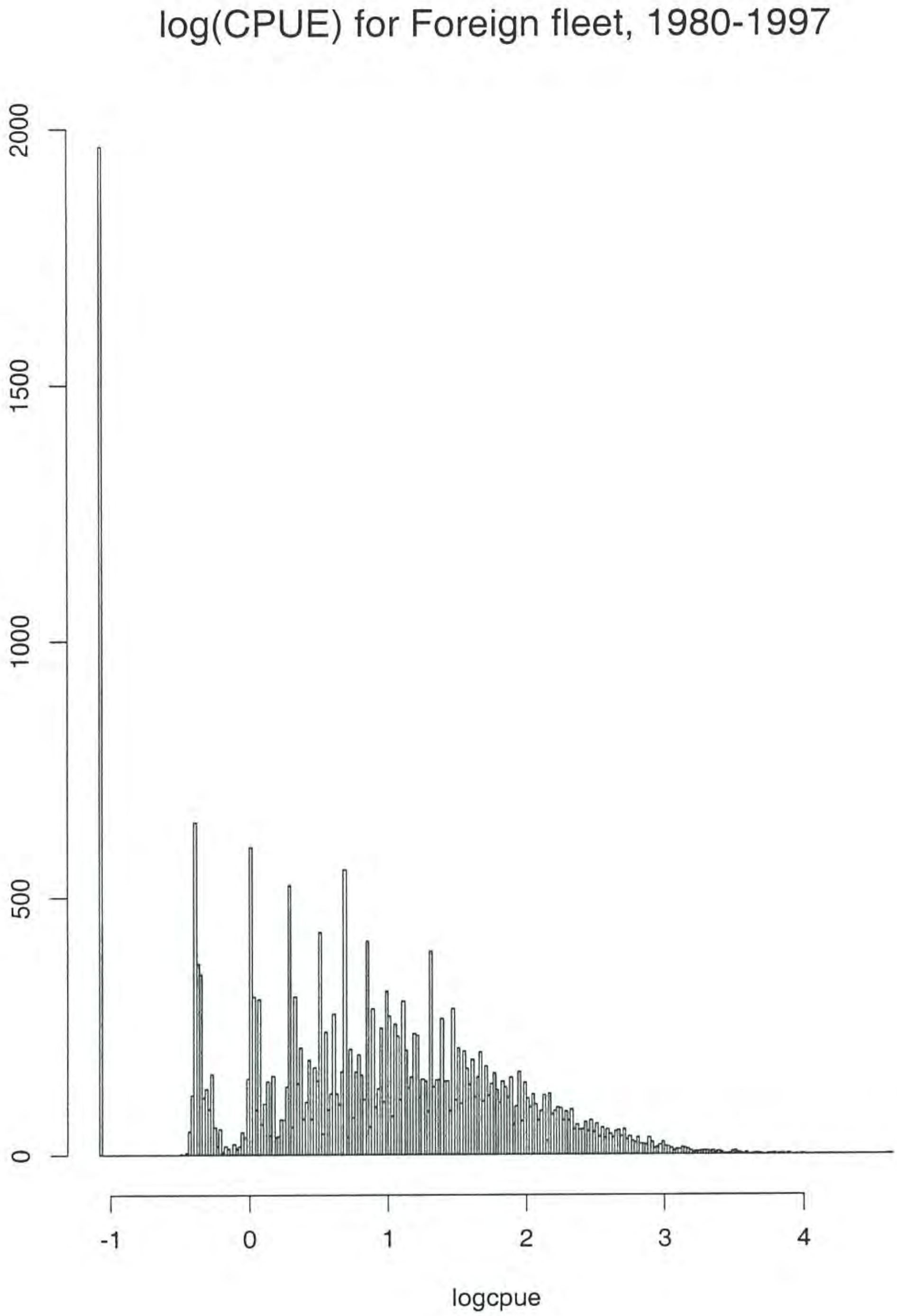

Figure 2.1: EAST CAPE Histogram of $\log(CPUE + \delta)$ from the East Coast region, 1980-1997. Only the foreign fleet is included, and δ is a small positive constant added so that zero CPUE can be plotted.

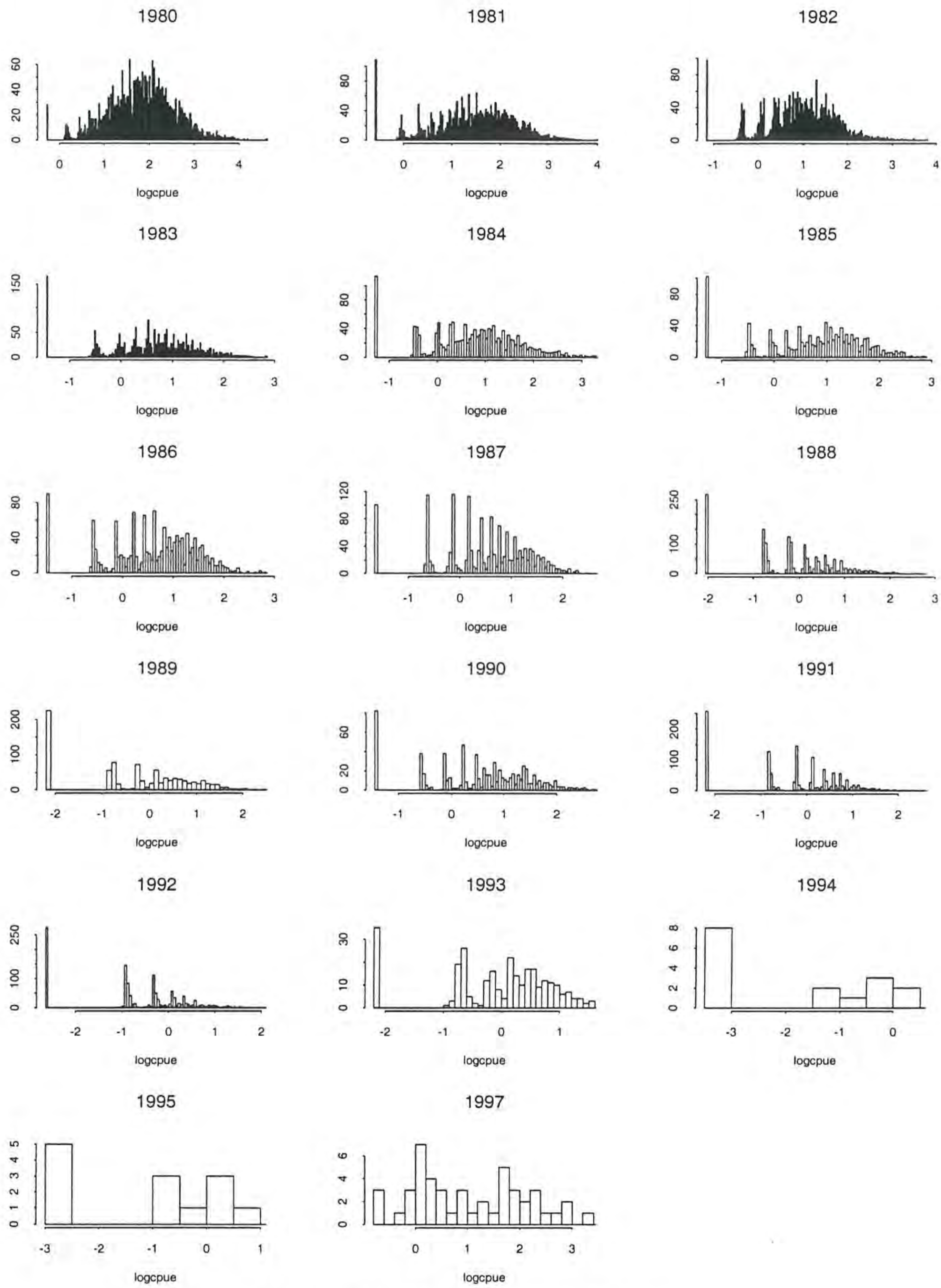

Figure 2.2: As in Figure 2.1, except data plotted by year.

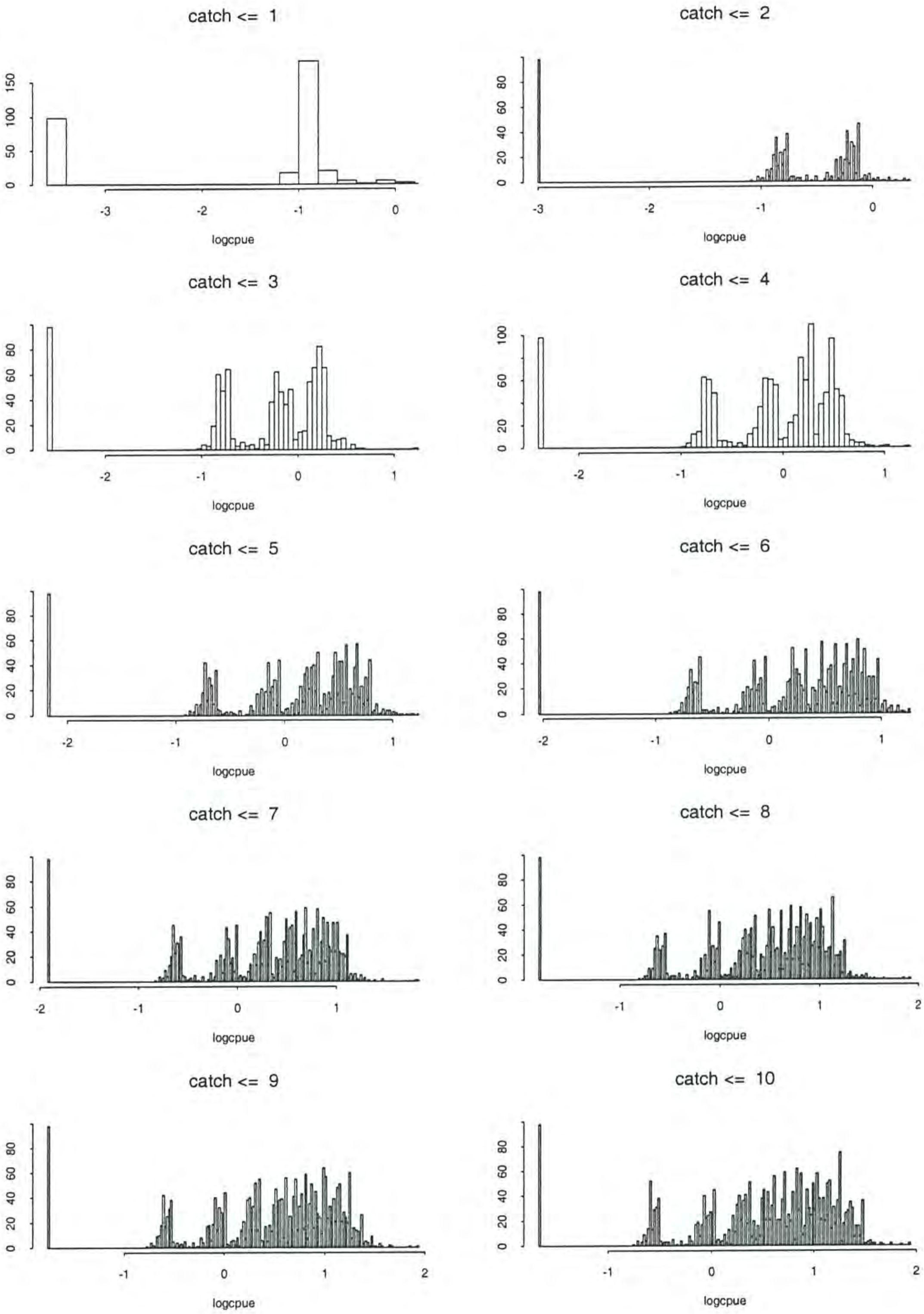

Figure 2.3: Histograms of CPUE, as above, but for 1982 and separately for catches between 1 and 10

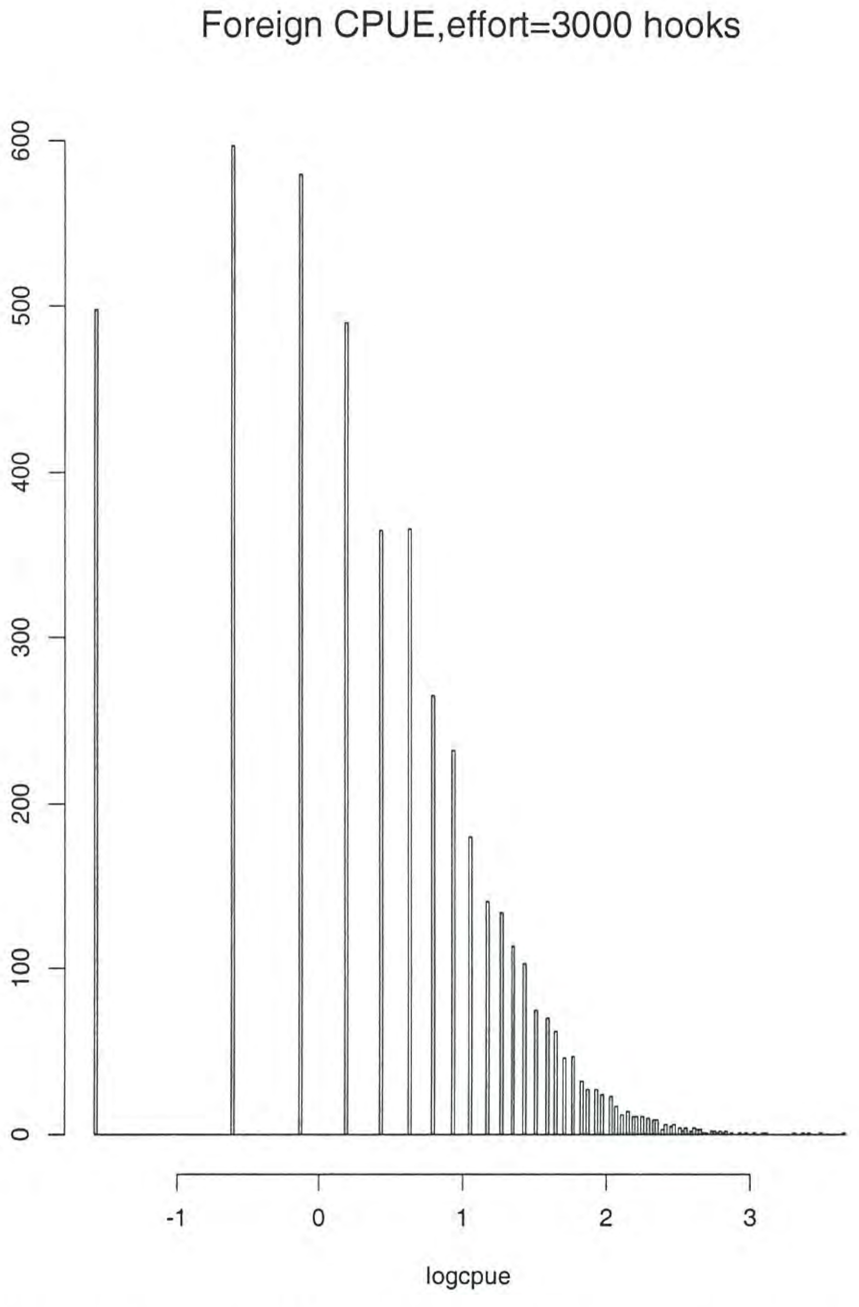

Figure 2.4: Histograms of CPUE, as above, in 1980-1997 for an effort of 3000 hooks

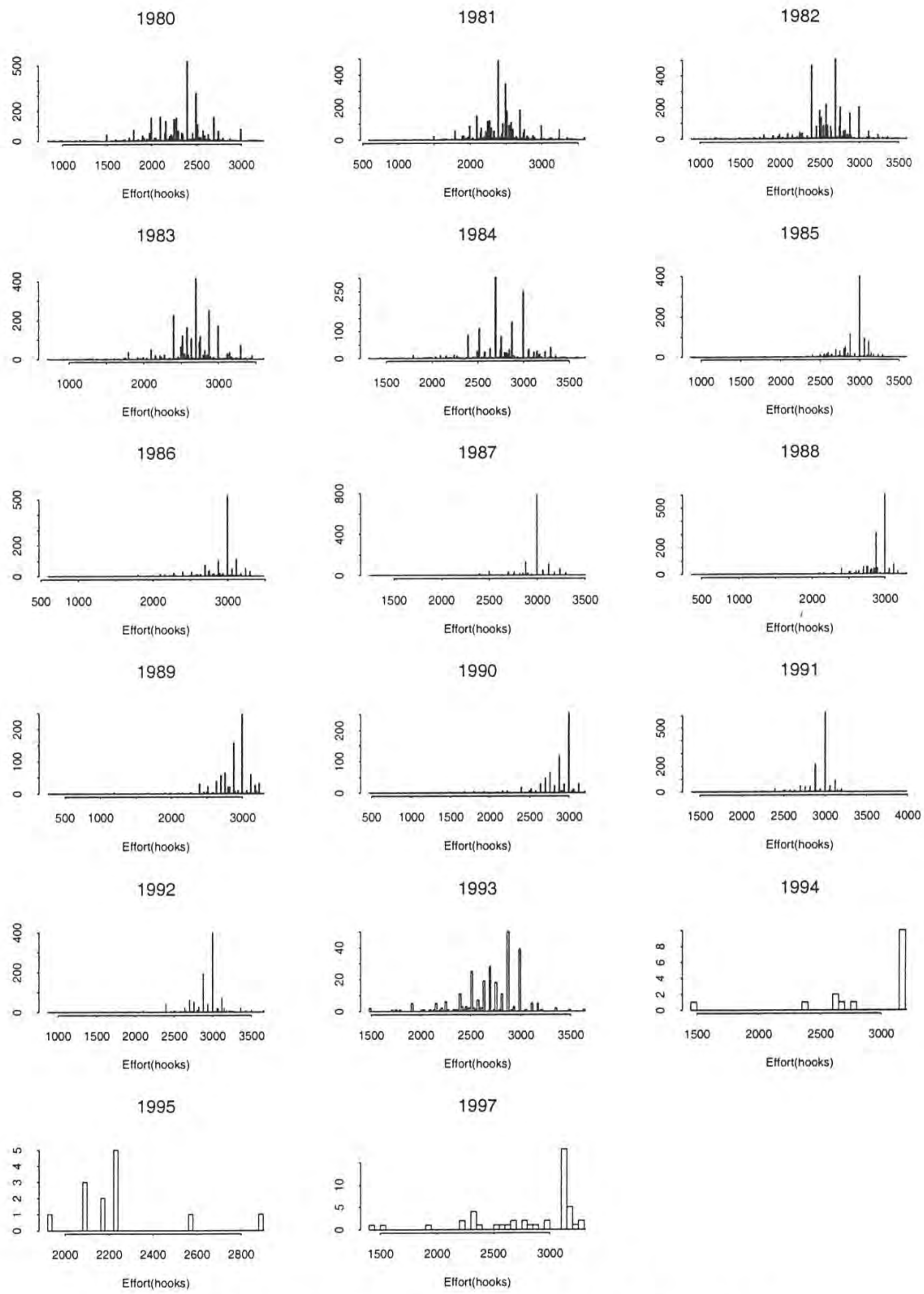

Figure 2.5a: Histograms of effort between 1980-1997 for the foreign fleet

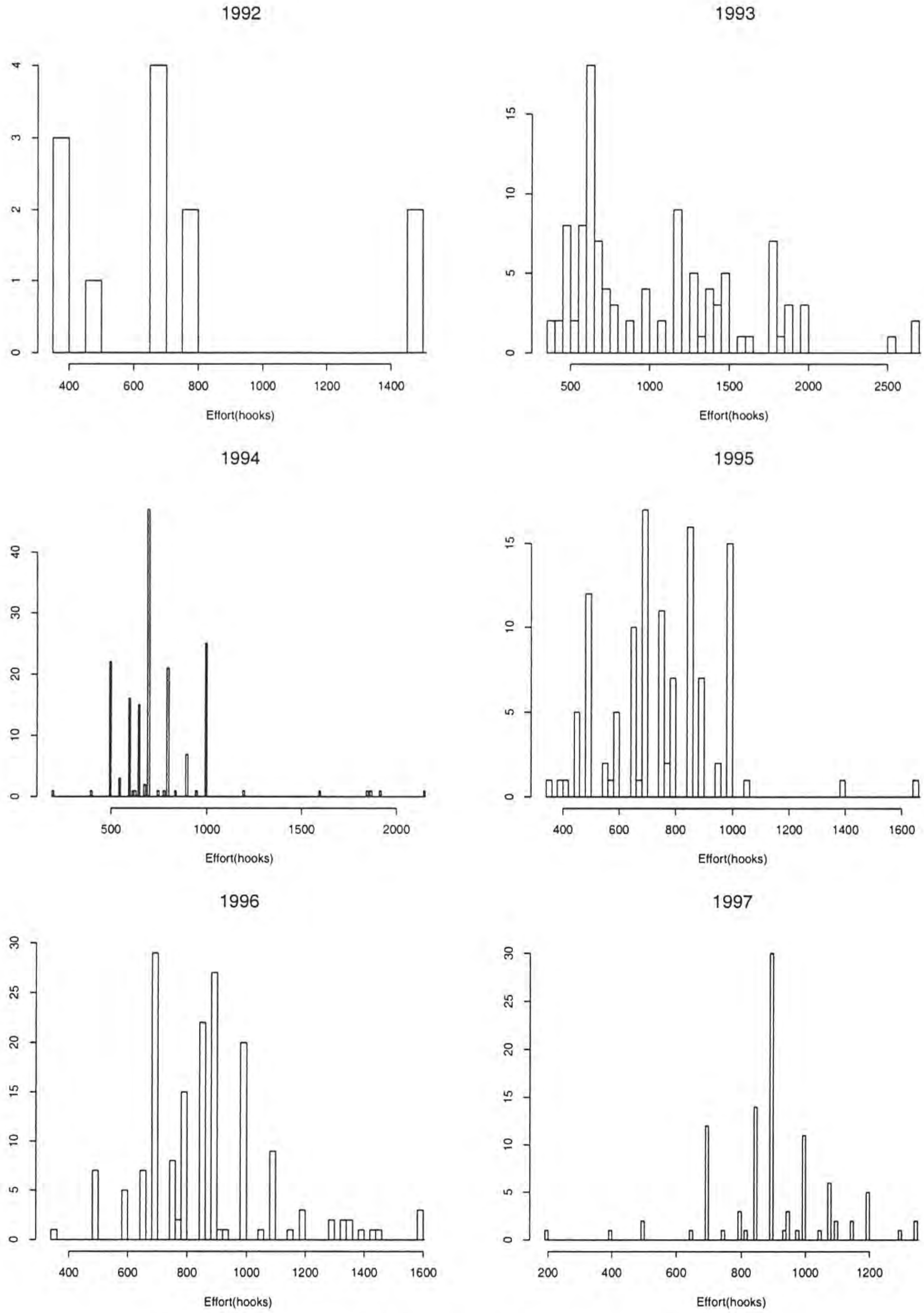

Figure 2.5b: Histograms of effort between 1980-1997 for the domestic fleet

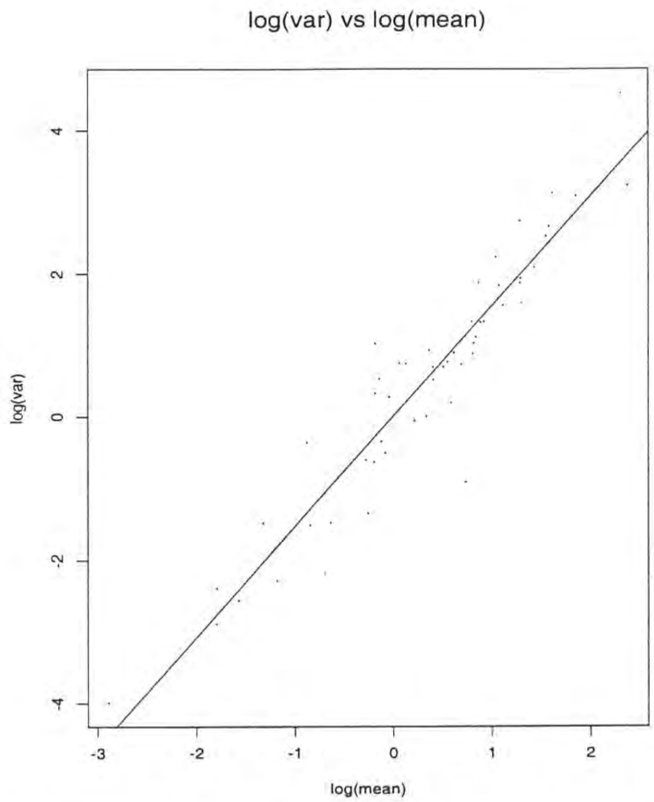

Figure 2.6a: log(mean) -log(variance) plots for CPUE data from the East Coast region with effort=3000hooks

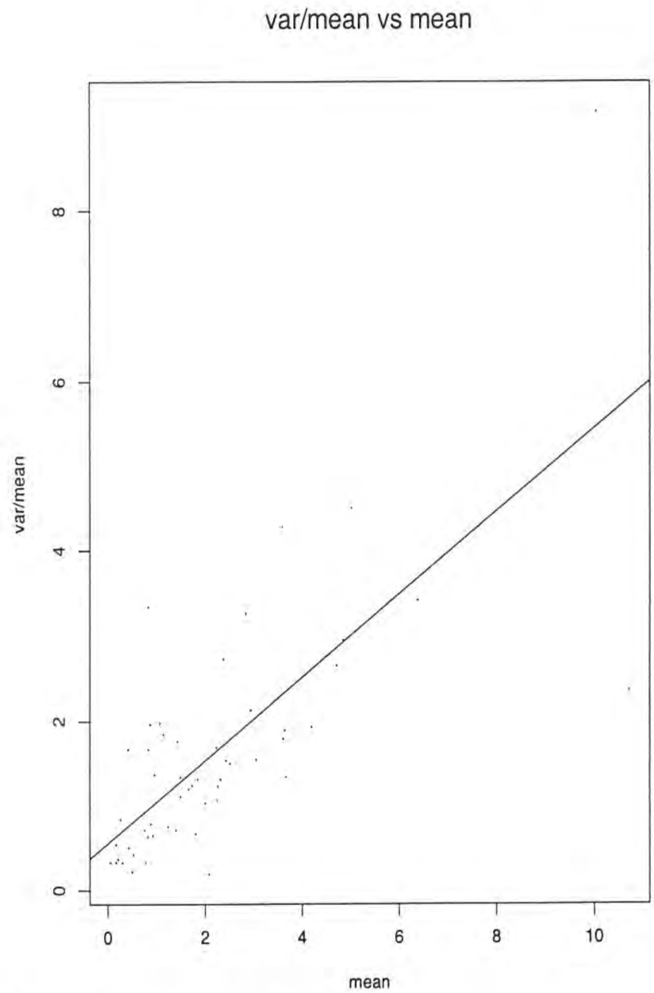

Figure 2.6b: variance/mean -mean plot for positive CPUE data from the East Coast region with effort=3000hooks

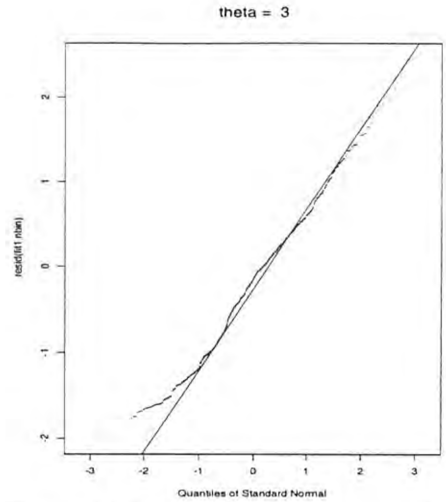

Figure 2.7a: qq plot for negative binomial response model of 1987 East Coast foreign fleet CPUE data at a fixed effort of 3000 hooks.

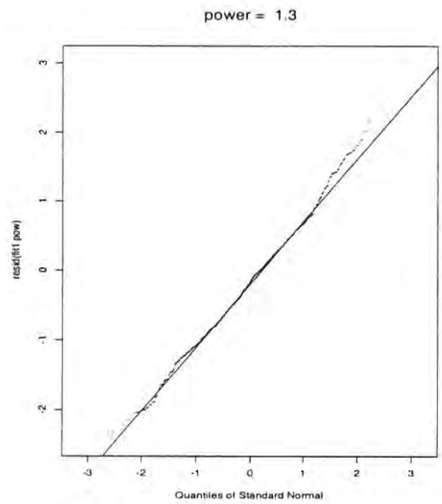

Figure 2.7b: qq plot for power law response model of 1987 East Coast foreign fleet CPUE data at a fixed effort of 3000 hooks

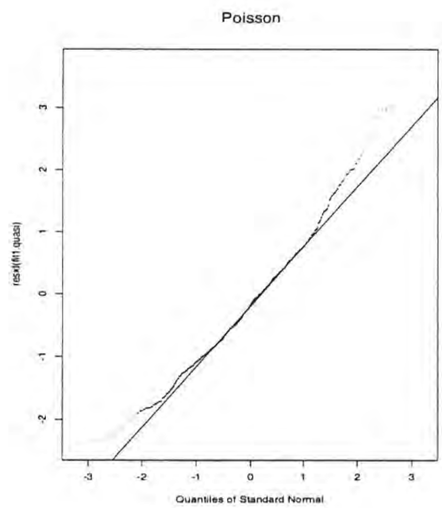

Figure 2.7c: qq plot for Poisson response model of 1987 East Coast foreign fleet CPUE data at a fixed effort of 3000 hooks

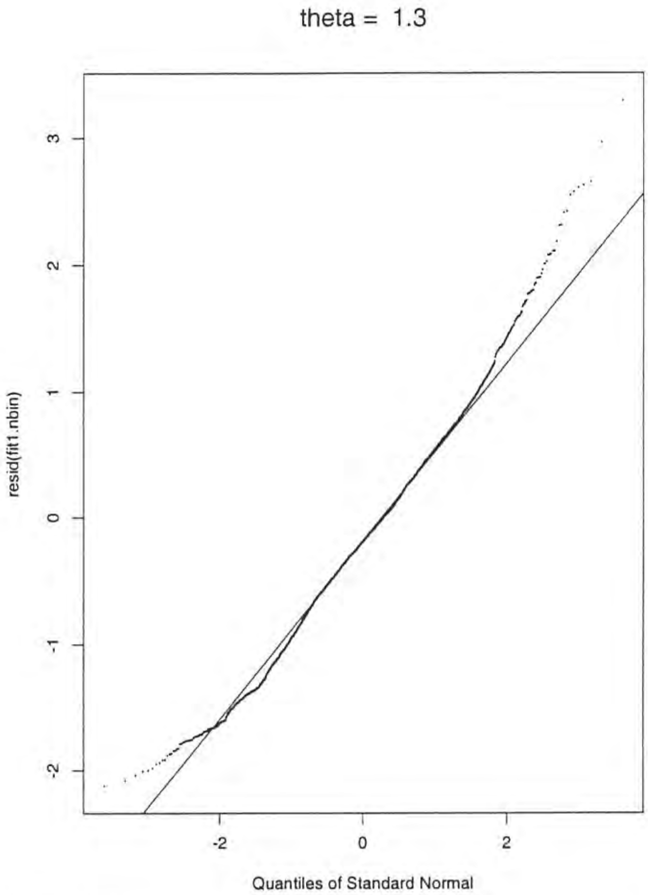

Figure 2.8a qq plot for negative binomial response model of 1982 East Coast foreign fleet CPUE data

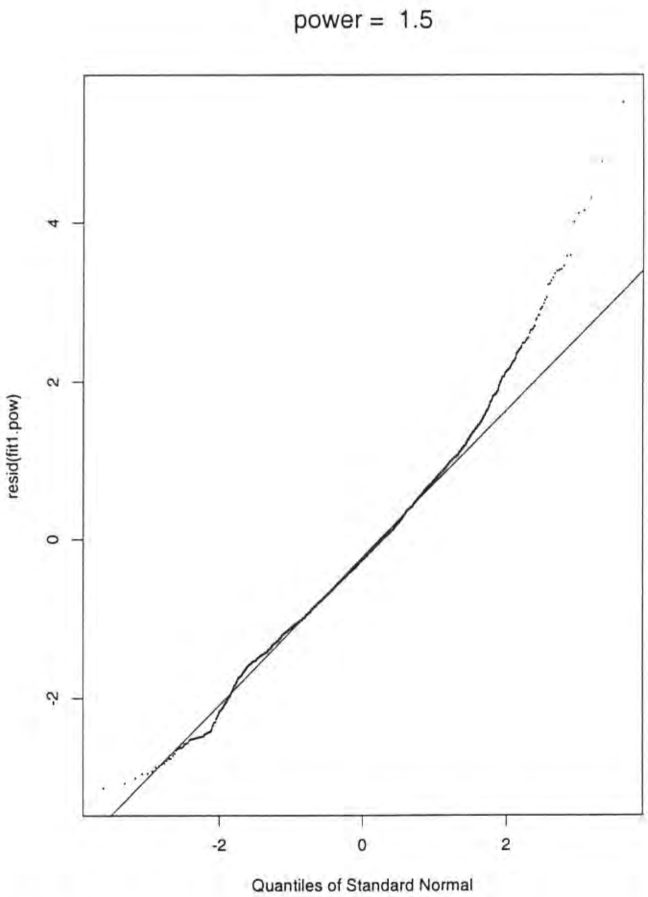

Figure 2.8b qq plot for power-law response model of 1982 East Coast foreign fleet CPUE data

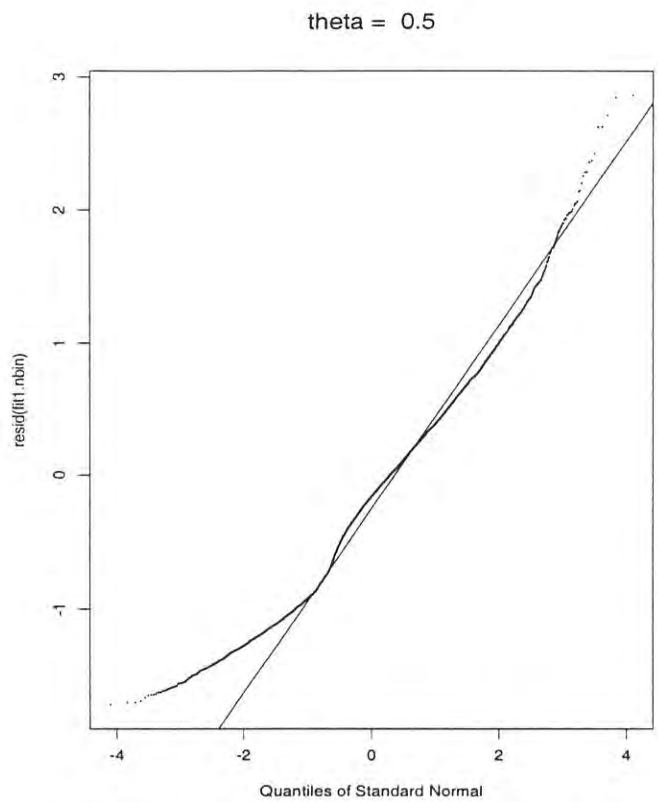

Figure 2.9a qq plot for negative binomial response model of East Coast foreign fleet CPUE data

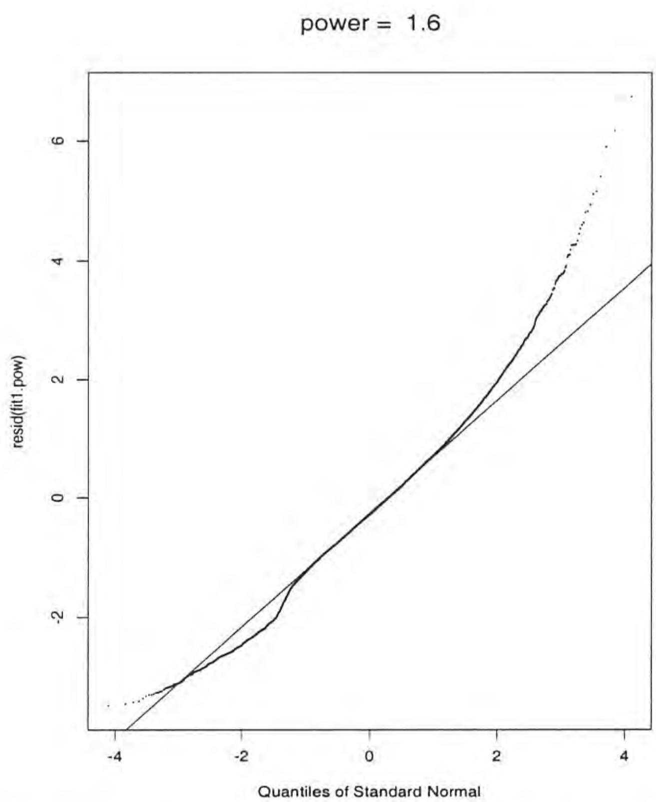

Figure 2.9b qq plot for power-law response model of East Coast foreign fleet CPUE data

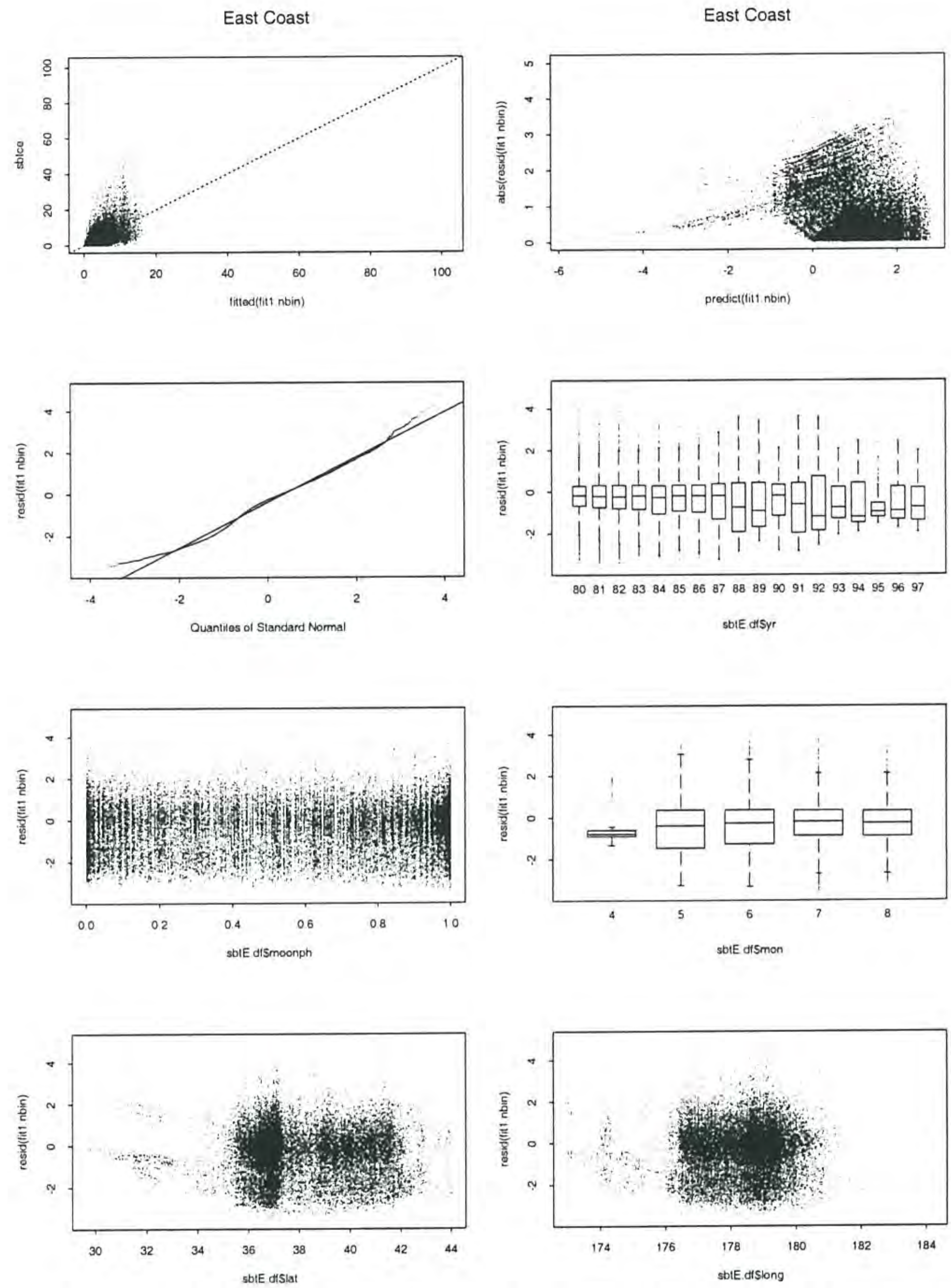

Figure 2.10a Residual plots for the negative binomial response model of East Coast CPUE data Call: glm(formula = sbtce ~ yr + poly(moonph, 3) + mon + poly(lat, 3) + poly(long, 3), family = neg.binfn(0.3), data = sbtE.df, weights = wt2^0.3)

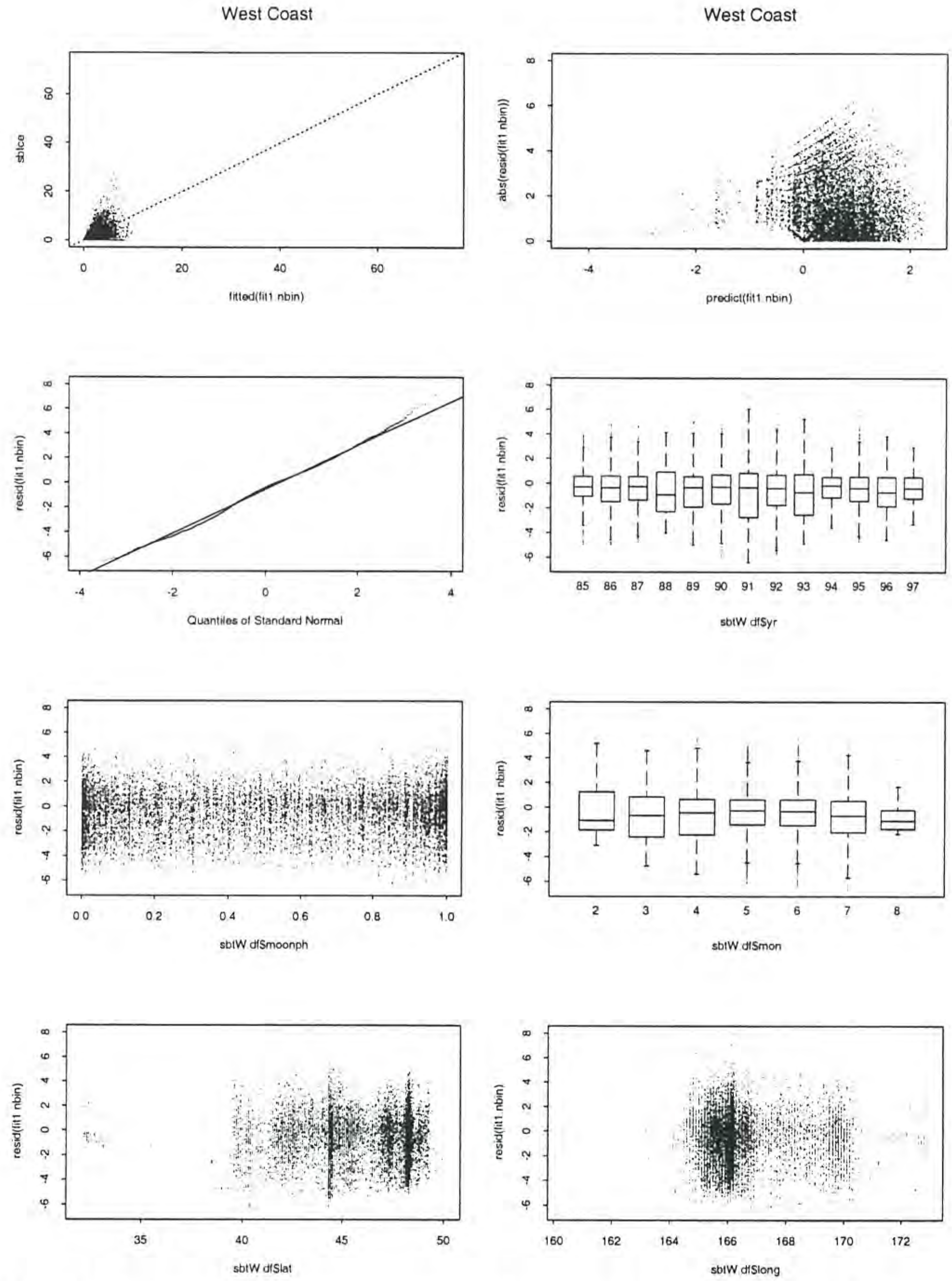

Figure 2.10b Residual plots for the negative binomial response model of West Coast CPUE data Call: glm(formula = sbtce ~ yr + poly(lat, 3) + poly(moonph, 3) + mon + poly(long, 2), family = neg.binfn(1), data = sbtW.df, weights = wt2^0.4)

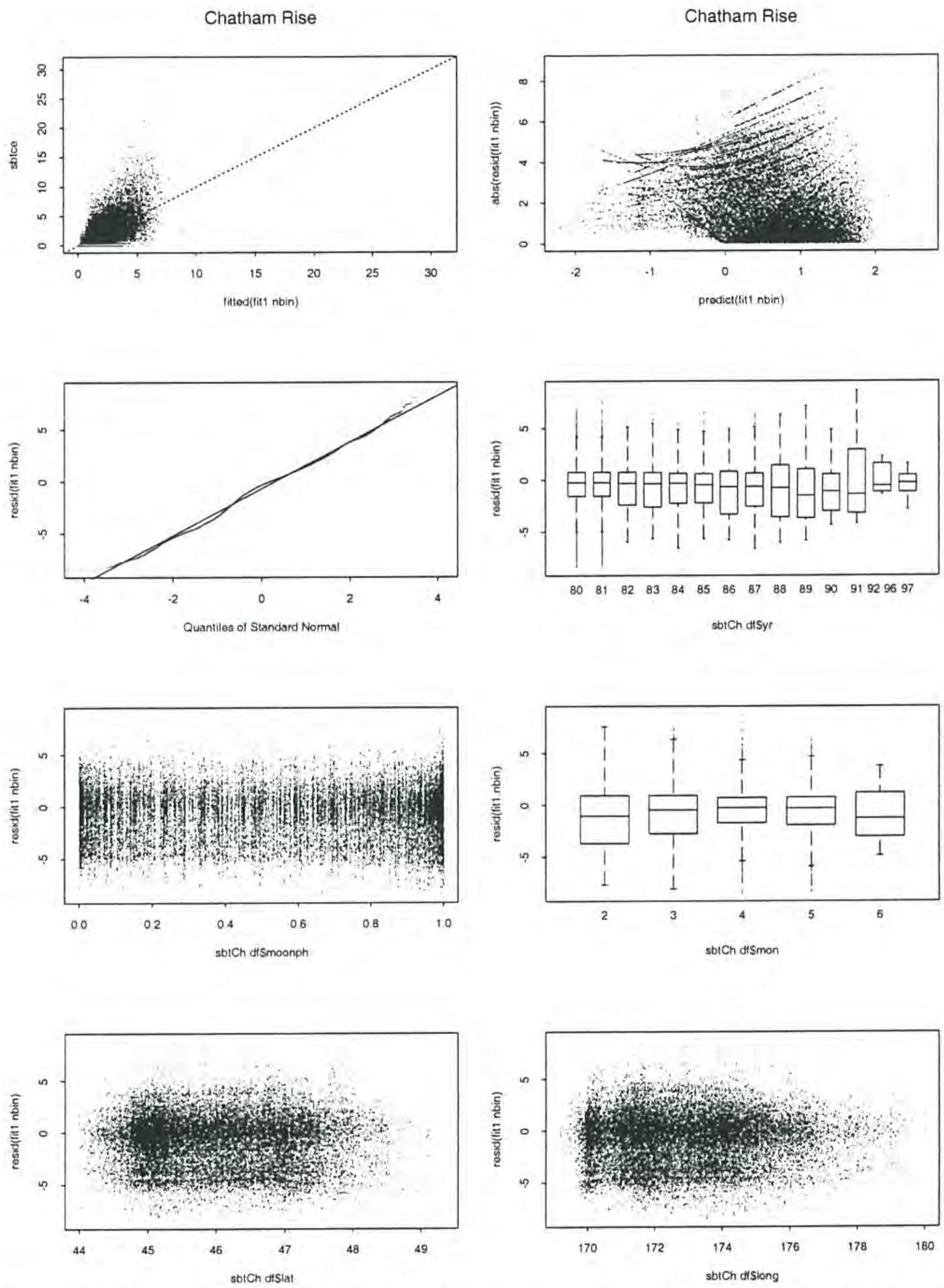

Figure 2.10c Residual plots for the negative binomial response model of Chatham Rise CPUE data
Call: glm(formula = sbtce ~ yrgrp + mon + poly(moonph, 3) + poly(long, 3) + poly(sst, 2) + poly(lat, 3), family = neg.binfn(0.5), data = sbtCh.df, weights = wt2^0.5)

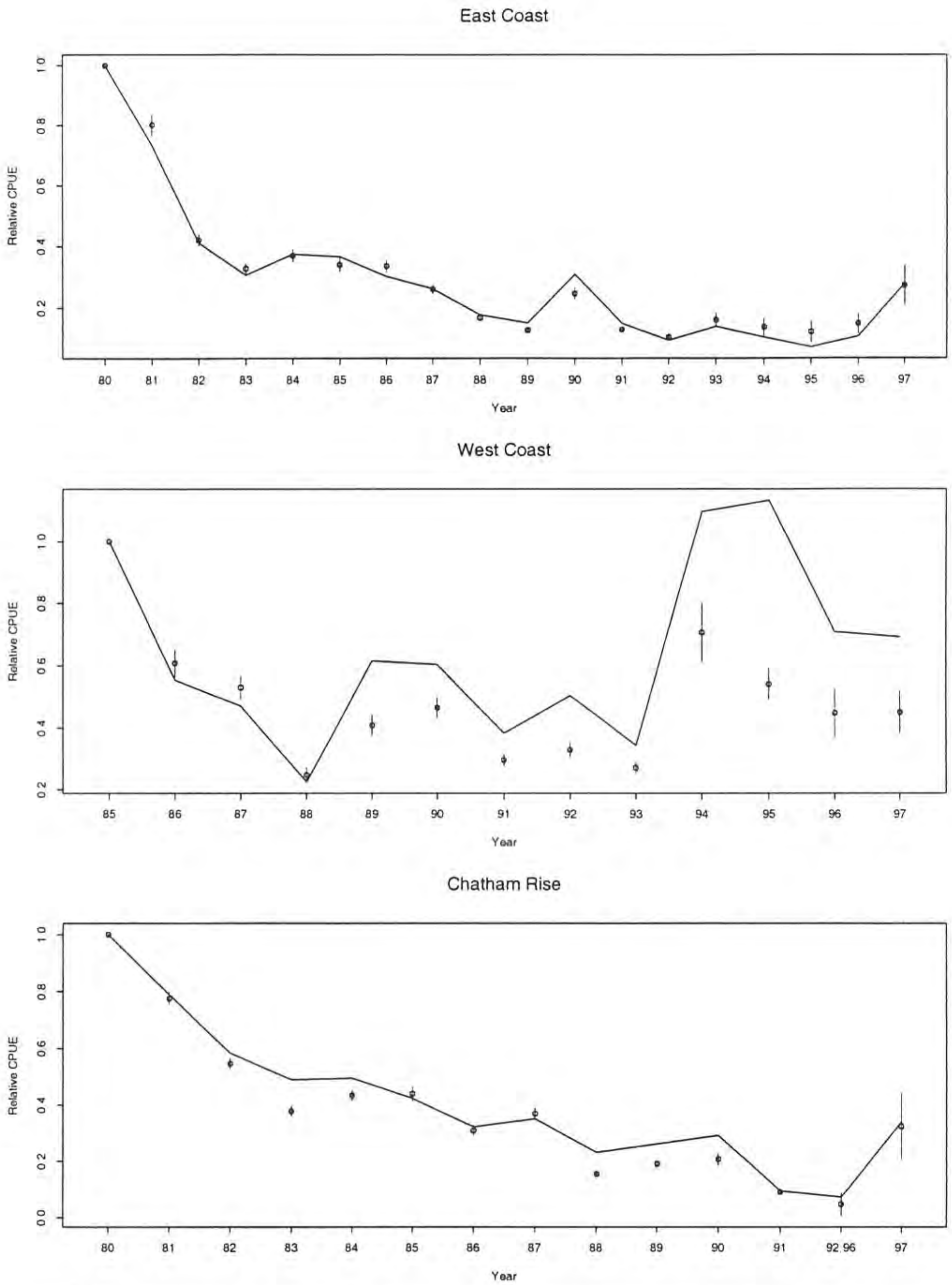

Figure 3.1: Estimated year coefficients from the negative binomial model for the East Cape, West Coast and Chatham Rise regions. The line connects relative mean CPUE from the same region and bars represent 2σ errors.

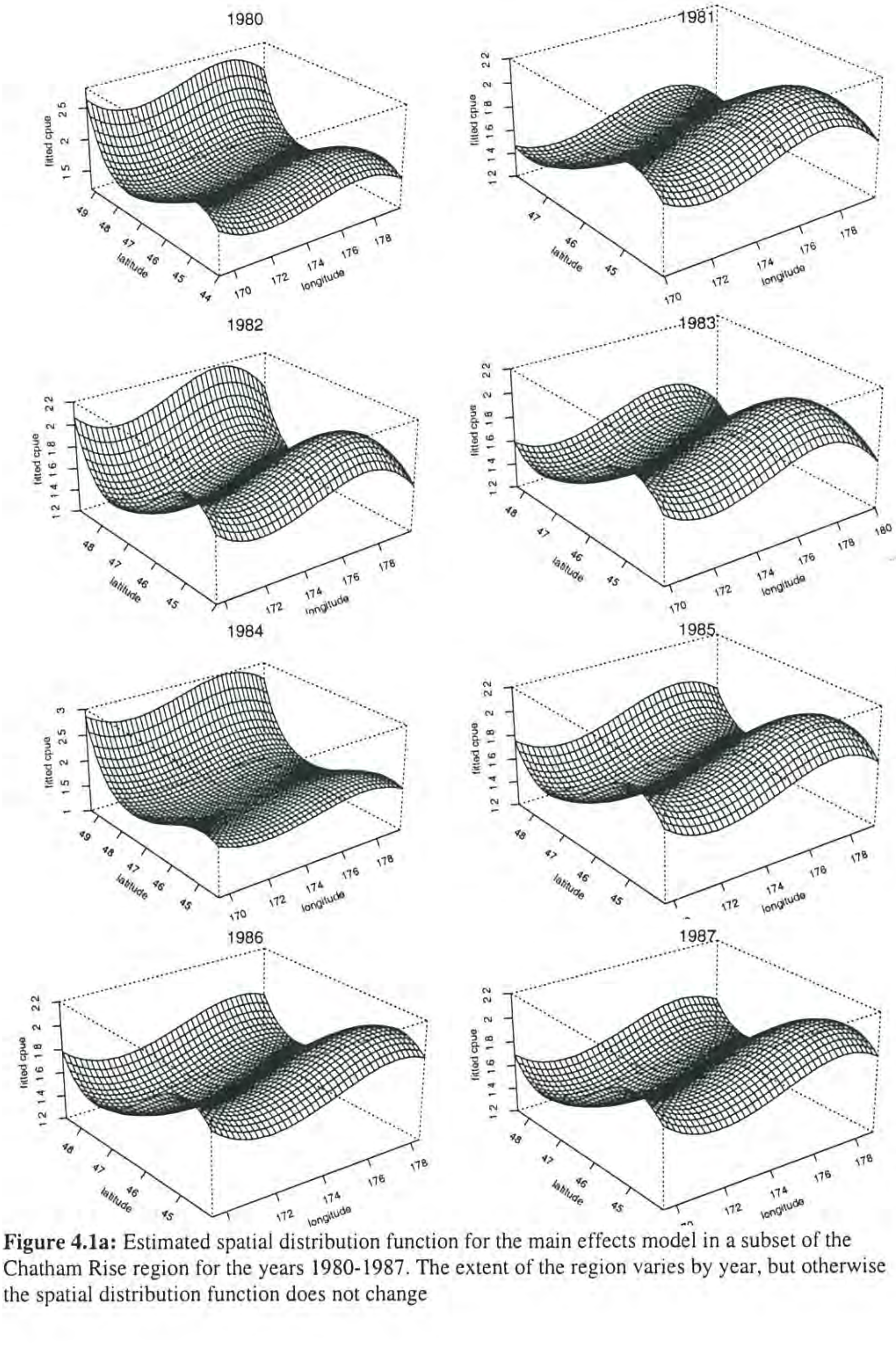

Figure 4.1a: Estimated spatial distribution function for the main effects model in a subset of the Chatham Rise region for the years 1980-1987. The extent of the region varies by year, but otherwise the spatial distribution function does not change

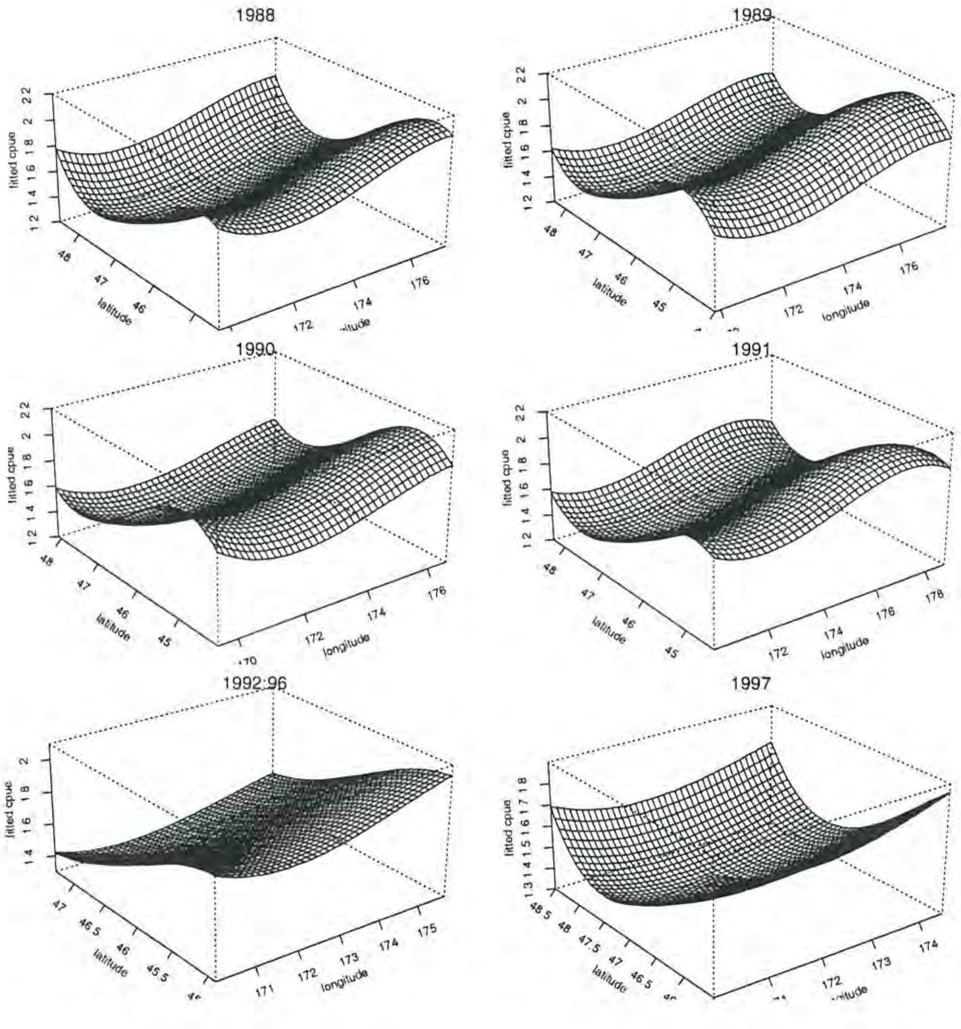

Figure 4.1b: As above, but for the years 1988-1997.

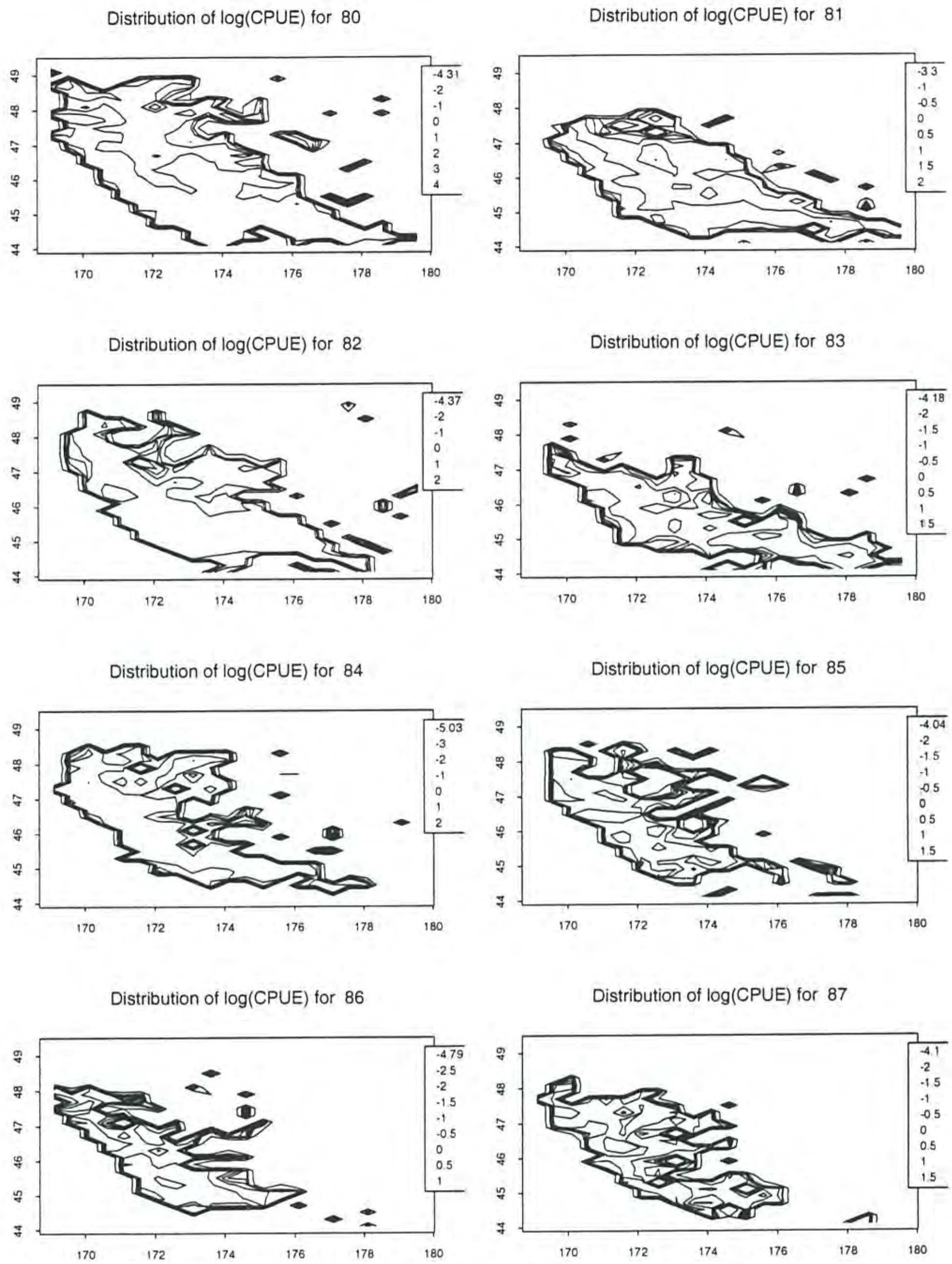

Figure 4.2a Contour plots of $\log(\mathrm{CPUE}+\delta)$ for the same region as in Figure 4.1

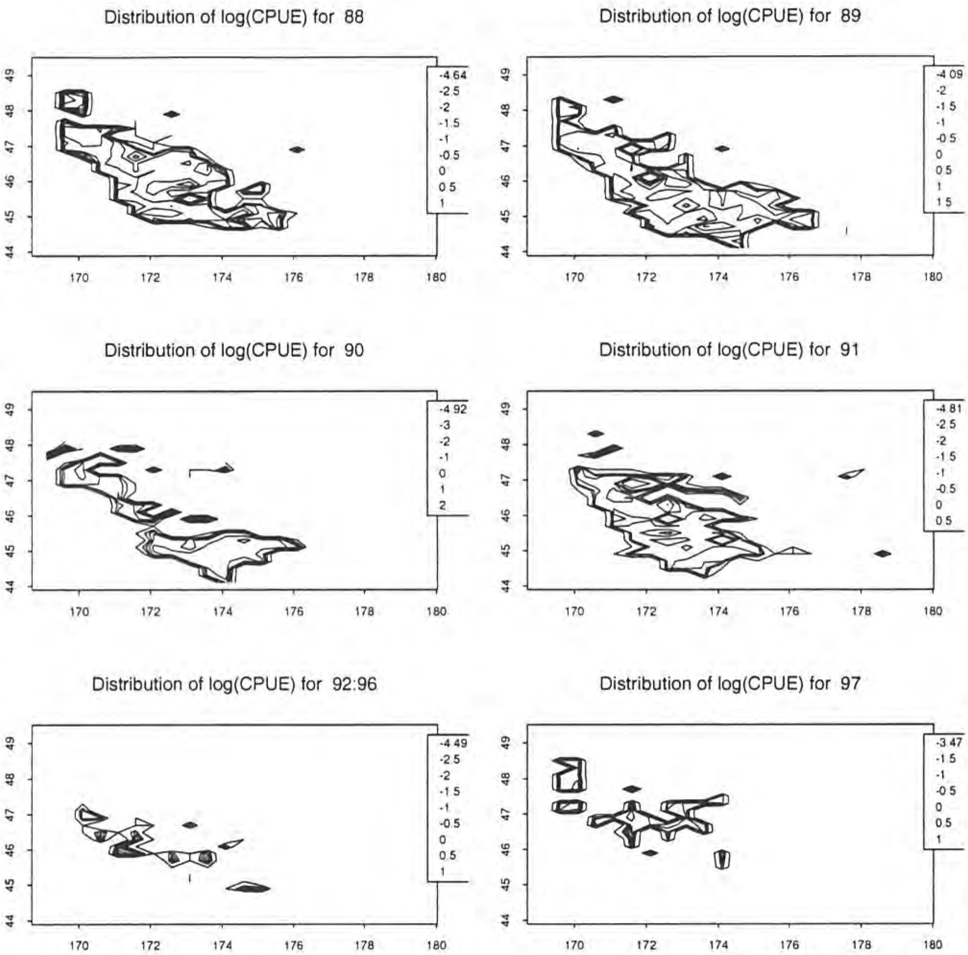

Figure 4.2b Contour plots of $\log(\text{CPUE} + \delta)$ for the same region as in Figure 4.1

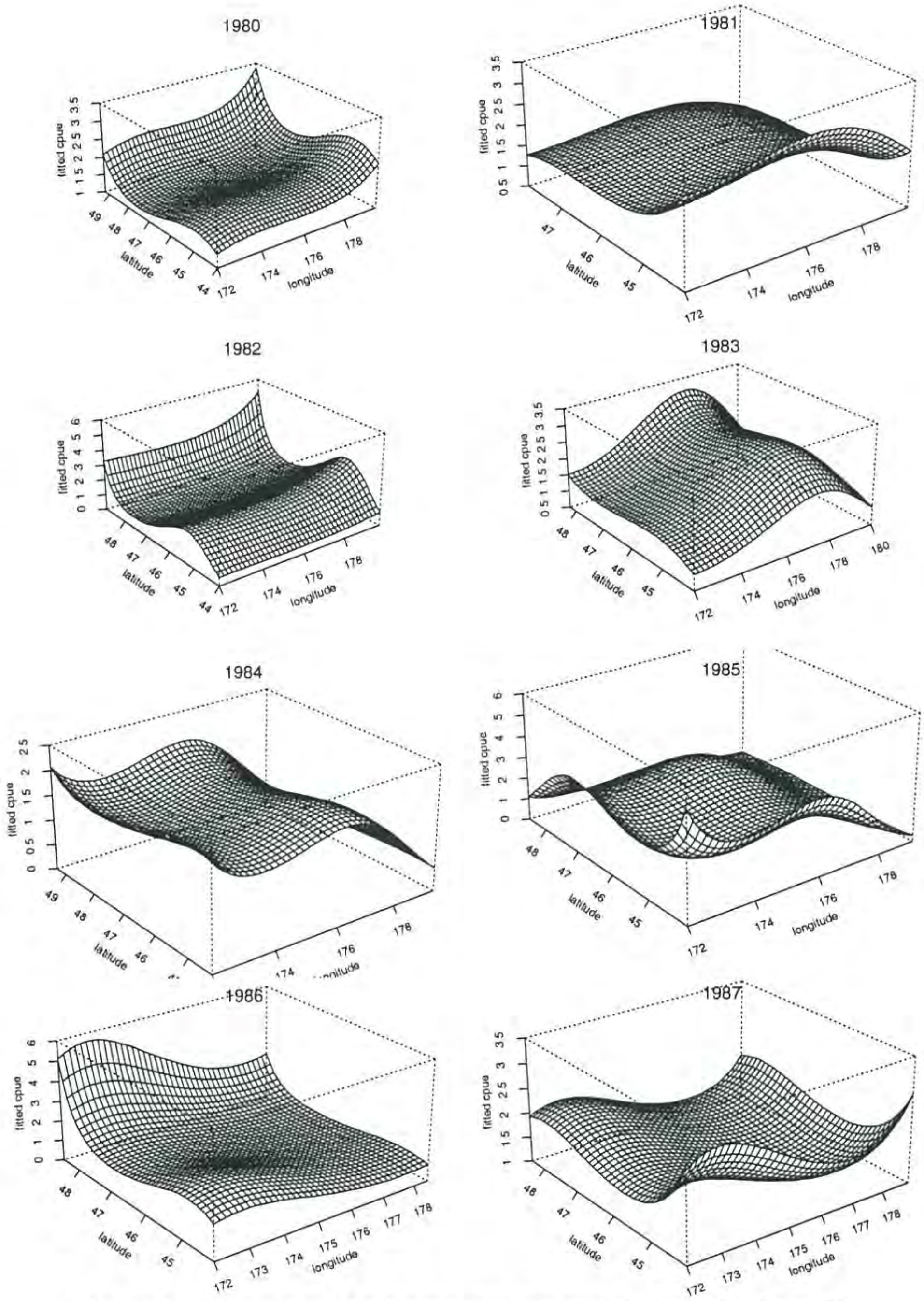

Figure 4.3a: As for Figure 4.1, but including *year:spatial* terms in the glm model

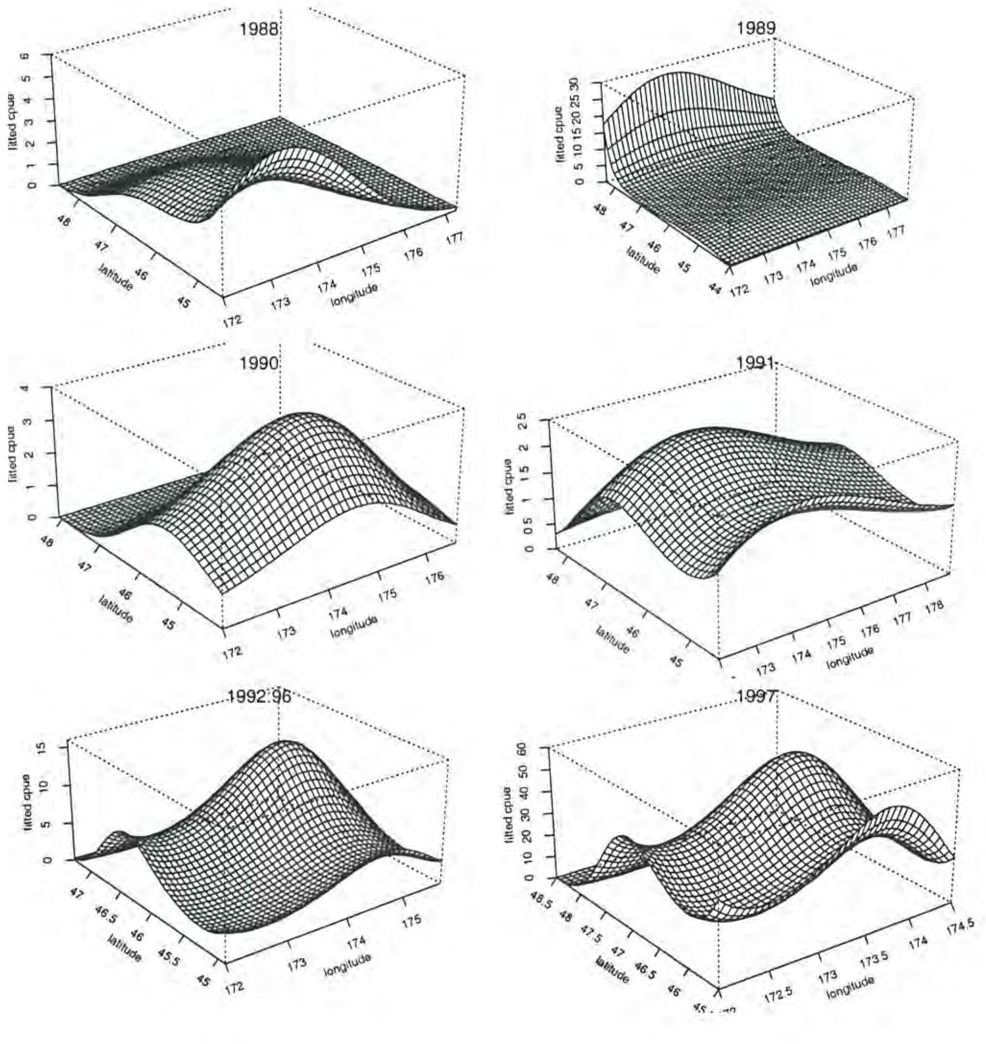

Figure 4.3b: As for Figure 4.1, but including *year:spatial* terms in the glm model

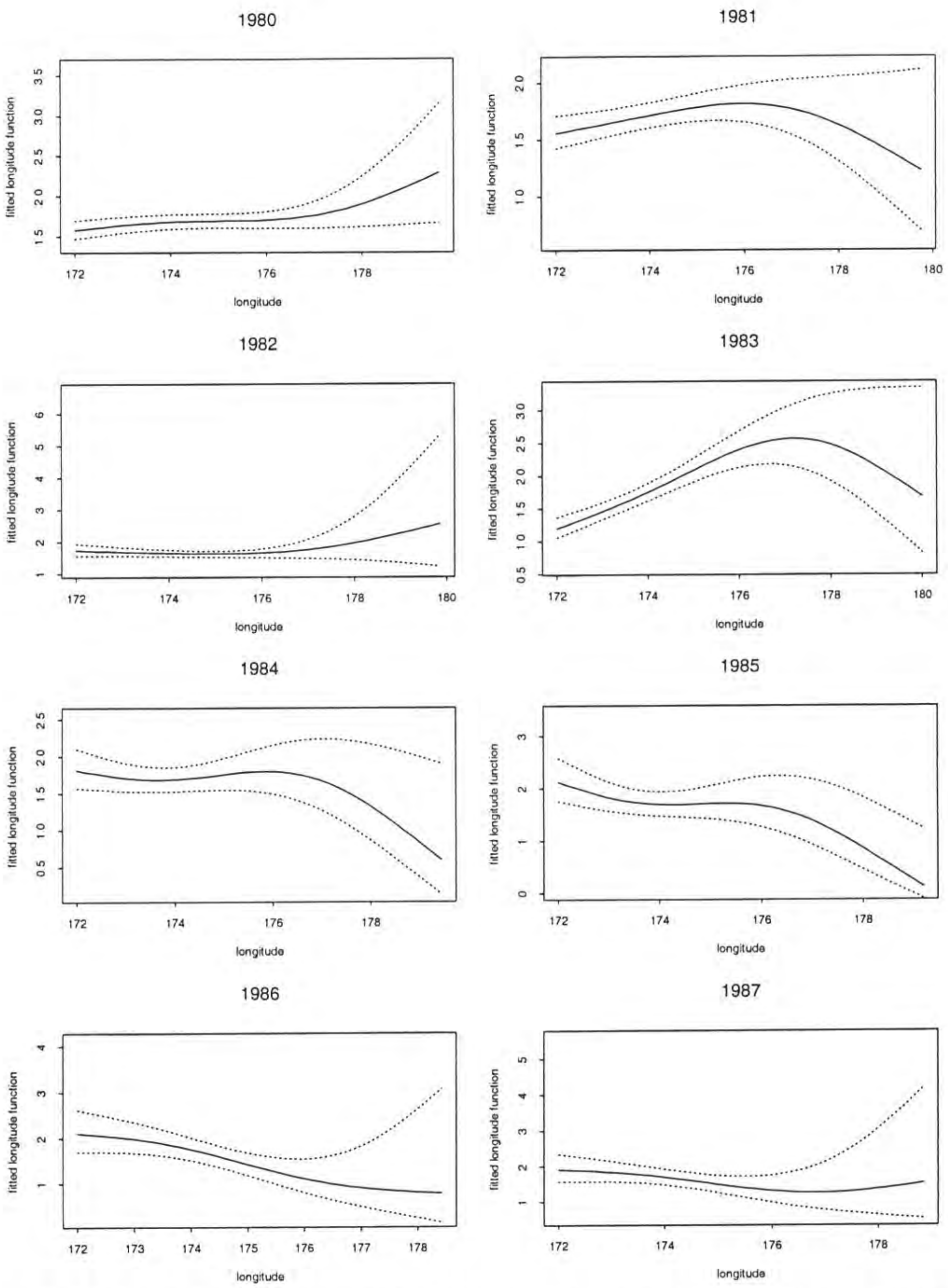

Figure 4.4a: Fitted longitude function for the GLM model which includes *year:spatial* terms (1980-1987). Dotted curves are 2σ standard errors.

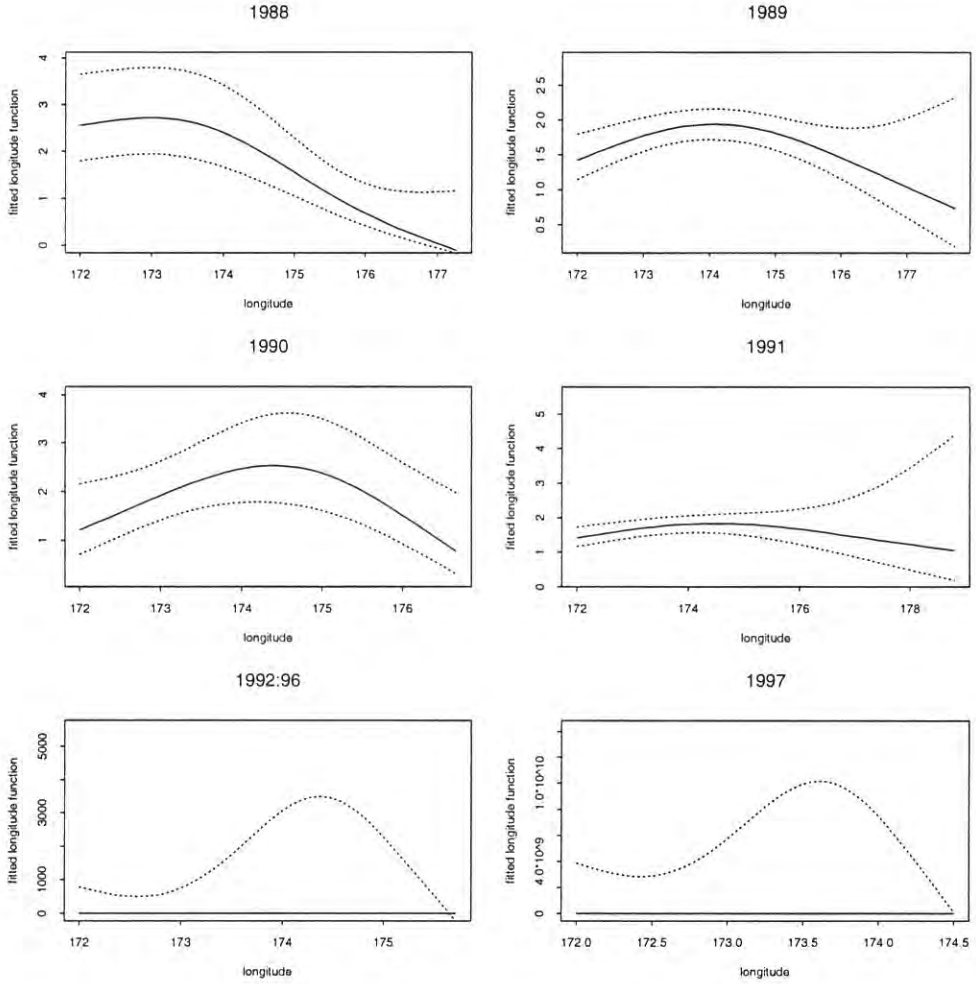

Figure 4.4b Fitted longitude function for the GLM model which includes *year:spatial* terms (1988-1997). Dotted curves are 2σ standard errors.

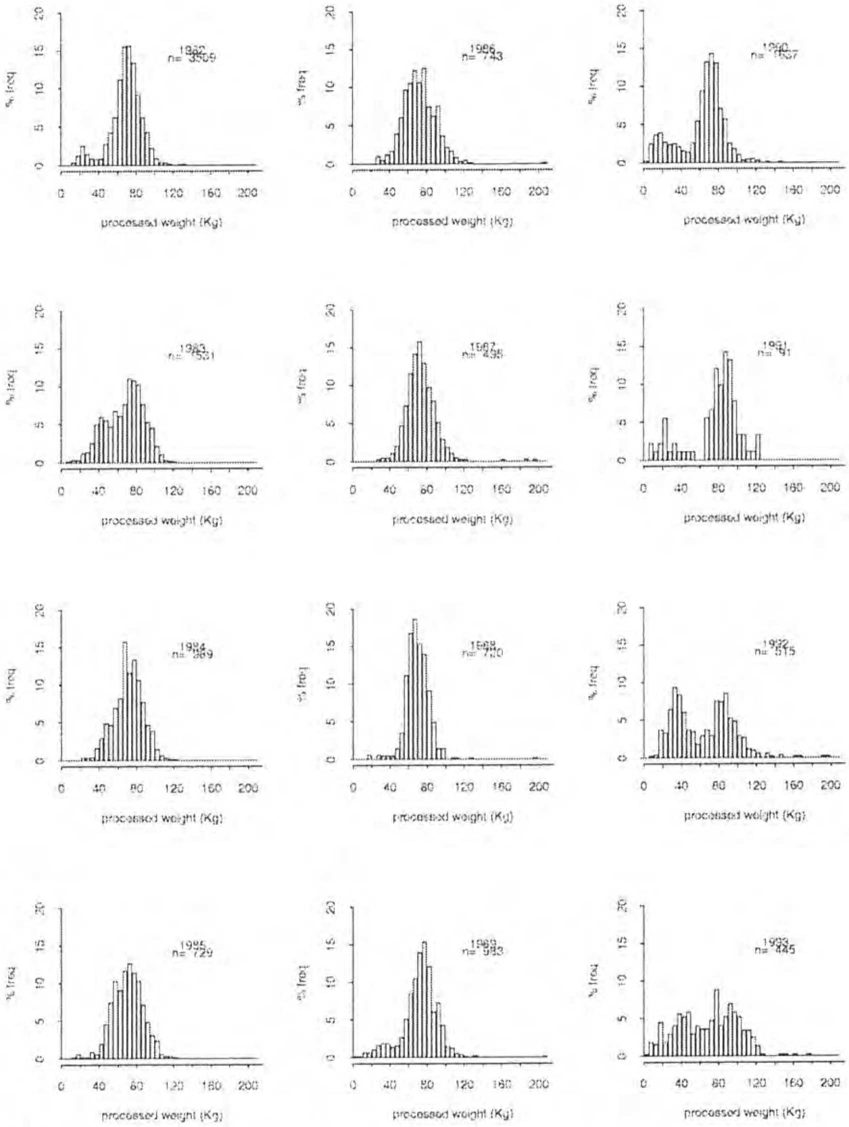

Figure 4.5a: Size composition in the Domestic fishery (including DanSol data), 1982-1993

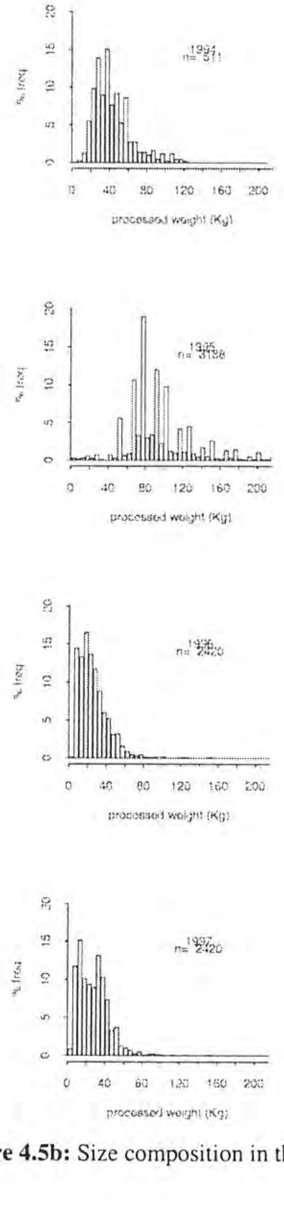

Figure 4.5b: Size composition in the Domestic fishery (including DanSol data) 1994-1997

APPENDIX 1: CPUE Data

Table 1.1:EAST CAPE

Year	No. sets	hooks	catch	cpue	No. zero sets	% zero sets	Year Index	S. Error
80	3348	7787	58993	7.6426	28	0.84	1	0
81	3409	8343	46654	5.6189	109	3.2	0.8065	0.0176
82	3305	8603	26918	3.1535	98	2.97	0.4267	0.0091
83	2429	6480	15253	2.3393	166	6.83	0.3332	0.0083
84	1483	4100	11741	2.862	113	7.62	0.3938	0.0116
85	1087	3158	8953	2.8021	102	9.38	0.3607	0.0118
86	1410	4039	9453	2.3085	90	6.38	0.3583	0.0107
87	1566	4639	9314	1.9982	101	6.45	0.2711	0.0072
88	1693	4843	6432	1.3511	267	15.77	0.182	0.0052
89	881	2507	2944	1.1486	225	25.54	0.1383	0.0054
90	719	2037	4806	2.3588	82	11.4	0.265	0.0105
91	1331	3876	4432	1.1407	262	19.68	0.1335	0.0039
92	1169	3365	2442	0.7162	285	24.38	0.1077	0.0039
93	388	870	993	1.0719	98	25.26	0.1693	0.0117
94	190	179	118	0.8013	127	66.84	0.1448	0.0144
95	132	119	63	0.5578	98	74.24	0.1311	0.0187
96	171	149	128	0.8228	108	63.16	0.1592	0.0174
97	148	225	717	2.1223	61	41.22	0.2926	0.0337

Table 1.2:WEST COAST

Year	No. sets	hooks	catch	cpue	No. zero sets	% zero sets	Year index	S. error
85	947	2728	10244	3.7172	9	0.95	1	0
86	1007	2883	5966	2.0594	38	3.77	0.6086	0.0217
87	1067	3077	5438	1.7529	84	7.87	0.5303	0.0192
88	714	2078	1735	0.8328	162	22.69	0.2474	0.0115
89	750	2145	4894	2.2903	62	8.27	0.4088	0.0165
90	1079	3172	7100	2.2452	36	3.34	0.4649	0.0162
91	1748	5174	7369	1.4221	152	8.7	0.2954	0.0095
92	1587	4641	8758	1.8757	118	7.44	0.3285	0.012
93	1239	3755	4843	1.2737	159	12.83	0.2705	0.0101
94	399	982	4271	4.078	38	9.52	0.7059	0.0464
95	923	1910	6212	4.2159	94	10.18	0.5404	0.0248
96	232	274	655	4.7771	55	23.71	0.4475	0.0388
97	289	809	2082	4.2613	25	8.65	0.45	0.0343

Table 1.3:CHATHAM RISE

Yeargrp	No sets	hooks	catch	cpue	No zero se	% zero sets	Year Index	S. Error
80	6088	15221	52809	3.4285	250	4.11	1	0
81	5320	13924	37976	2.7051	150	2.82	0.7746	0.0107
82	3254	8995	18286	2.0021	238	7.31	0.5455	0.0092
83	2214	6263	10504	1.6764	178	8.04	0.3777	0.0094
84	1981	5892	10003	1.6971	146	7.37	0.4335	0.0091
85	1229	3605	5246	1.4474	76	6.18	0.4397	0.0124
86	906	2722	3015	1.1067	99	10.93	0.309	0.0093
87	1287	3800	4583	1.2018	133	10.33	0.3687	0.0095
88	1479	4356	3455	0.792	330	22.31	0.1545	0.0045
89	1301	3852	3464	0.8958	207	15.91	0.1913	0.0053
90	464	1376	1382	1.0012	93	20.04	0.2073	0.01
91	799	2374	768	0.3232	331	41.43	0.0909	0.0035
92:96	53	150	29	0.2513	30	56.6	0.0474	0.02
97	94	284	334	1.1645	8	8.51	0.3236	0.0573

APPENDIX 2: Model Deviance Residuals

Table 2.1:East Cape

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
NULL			24858	49847.38		
yr	17	11779.81	24841	38067.58	792.2232	0.00E+00
poly(moonph, 3)	3	2165.32	24838	35902.26	825.201	0.00E+00
mon	4	1704.47	24834	34197.79	487.1774	0.00E+00
poly(lat, 3)	3	653.56	24831	33544.23	249.0691	0.00E+00
poly(long, 3)	3	38.4	24828	33505.83	14.6355	1.61E-09

fit1.nbin<-glm(sbtce~year+poly(moonphase,3)+month+poly(lat,3)+poly(long,3),
data=sbtE.df,family=neg.binfn(0.3),weights=wt2^0.3)

Table 2.2:West Coast

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
NULL			11974	59486.67		
yr	12	8125.544	11962	51361.12	262.3764	0
poly(lat, 3)	3	3601.566	11959	47759.56	465.1828	0
poly(moonph, 3)	3	1570.803	11956	46188.75	202.887	0
mon	6	1452.835	11950	44735.92	93.825	0
poly(long, 2)	2	287.718	11948	44448.2	55.743	0

fit1.nbin<-glm(sbtce~year+poly(lat,3)+poly(moonphase,3)+month+poly(long,2),
data=sbtW.df,family=neg.binfn(1),weights=wt2^0.4)

Table 2.3:Chatham Rise

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
NULL			26468	216122.8		
yrgrp	13	38069.74	26455	178053.1	860.1069	0
mon	4	12352.71	26451	165700.4	907.0226	0
poly(moonph, 3)	3	7386.08	26448	158314.3	723.117	0
poly(long, 3)	3	1340.5	26445	156973.8	131.2388	0
poly(sst, 2)	2	440.74	26443	156533.1	64.7241	0
poly(lat, 3)	3	449.49	26440	156083.6	44.006	0

fit1.nbin<-glm(sbtce~yeargrp+mon+poly(moonphase,3)+poly(long,3)+poly(sst,2)+poly(lat,3),
data=sbtCh.df,family=neg.binfn(0.5),weights=wt2^0.5)

Table 2.4: Chatham Rise + hooks

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
NULL			16209	126843.6		
yrgrp	13	23113.03	16196	103730.6	554.9757	0.00E+00
mon	4	7504.51	16192	96226.1	585.6292	0.00E+00
poly(moonph, 3)	3	3493.22	16189	92732.8	363.4667	0.00E+00
poly(long, 3)	3	203.81	16186	92529	21.206	1.05E-13
poly(hooks, 3)	3	151.93	16183	92377.1	15.8077	2.92E-10
poly(sst, 2)	2	188.58	16181	92188.5	29.4325	1.74E-13
poly(lat, 3)	3	311.63	16178	91876.9	32.4246	0.00E+00
yrgrp:poly(long, 3)	39	641.99	16139	91234.9	5.1384	0.00E+00
yrgrp:poly(lat, 3)	39	742.4	16100	90492.5	5.942	0.00E+00

```
fit1.nbin_glm(sbtce~yrgrp+mon+poly(moonph,3)+poly(long,3)+poly(hooks,3)+ poly(sst, 2)
        + poly(lat, 3) + yrgrp:poly(long, 3)+yrgrp:poly(lat,3),data=sbtCh.df,
              family=neg.binfn(0.5),weights=wt2^0.5,subset=(long>=172))
```

APPENDIX 3: Fisheries Indicators

Summary of annual longline fishing effort (millions of hooks) and SBT catch (whole weight, kg) in the New Zealand EEZ by fleet, Domestic refers to New Zealand owned and operated and chartered vessels while Japan refers only to foreign licensed vessels.

Fleet	Year	Longline Effort millions of hooks	Catch, tonnes
Domestic	1987	0.000	59.3
Domestic	1988	0.000	94.0
Domestic	1989	1.426	437.2
Domestic	1990	1.551	529.2
Domestic	1991	1.133	164.5
Domestic	1992	1.842	59.9
Domestic	1993	2.487	216.6
Domestic	1994	2.280	277.0
Domestic	1995	3.405	436.4
Domestic	1996	1.775	139.3
Domestic	1997	2.858	333.7
Japan	1980	25.899	7609.5
Japan	1981	26.191	5935.6
Japan	1982	23.651	3165.5
Japan	1983	15.694	1860.4
Japan	1984	12.827	1736.6
Japan	1985	11.779	1977.9
Japan	1986	13.020	1538.1
Japan	1987	16.766	1867.4
Japan	1988	12.943	1059.3
Japan	1989	8.192	760.7
Japan	1990	7.003	880.8
Japan	1991	12.068	905.6
Japan	1992	7.016	585.3
Japan	1993	3.059	250.8
Japan	1994	0.130	26.2
Japan	1995	0.211	37.3

Appendix 4 :

Summary of annual average SBT processed weight (kg) and CPUE (number per 1000 hooks) in the New Zealand EEZ by fleet, Domestic refers to New Zealand owned and operated vessels while Japan refers to both foreign licensed and chartered vessels.

Fleet	Year	Average SBT weight	Nominal CPUE
Domestic	1991	48.33	0.042
Domestic	1992	68.07	0.222
Domestic	1993	49.65	0.287
Domestic	1994	50.59	0.420
Domestic	1995	39.69	1.405
Domestic	1996	52.23	0.604
Domestic	1997	35.50	0.967
Japan	1980	55.26	4.624
Japan	1981	56.77	3.471
Japan	1982	58.72	1.982
Japan	1983	61.74	1.670
Japan	1984	64.40	1.828
Japan	1985	66.61	2.192
Japan	1986	70.66	1.454
Japan	1987	74.33	1.303
Japan	1988	77.36	0.920
Japan	1989	79.02	1.202
Japan	1990	68.53	1.652
Japan	1991	64.25	1.033
Japan	1992	60.36	1.305
Japan	1993	62.46	1.253
Japan	1994	56.87	4.115
Japan	1995	57.53	2.573

APPENDIX IX: Summary of tuna and swordfish discards and status on landing on tuna longliners.

A. Summary of landing and handling status of albacore

Data are summarised by fishing year from 1 October 1991 - 30 September 1997. Landing and handling status codes were not recorded by observers prior to 1992.

Status of ALB	Number
Retained	16736
Discarded	571
Lost	110
Unknown	258

571 albacore were discarded:

41 were landed alive
- 12 released because they were small
- 29 released but the reason was not recorded by the observers

298 were landed dead:
- 6 small and discarded
- 227 damaged (226 by sharks, 1 by an orca)
- 65 discarded but the reason was not recorded by the observers

232 were recorded as discarded with no further information

110 albacore were lost:
- 89 escaped alive
- 11 were dead and fell off the hook at the side of the boat
- 10 were recorded as lost but it is not known whether they were dead or alive

The status of 258 albacore was unknown:

no information was recorded as to whether these fish were dead or alive, or whether they were retained or discarded

Albacore discarded, or lost, by year:

Year	number of ALB retained	discarded			lost			status unknown
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown	
1991-92	2991	4	34					2
1992-93	3187	17	69	22	3		10	8
1993-94	767	3	23					151
1994-95	1809	4	41		1			8
1995-96	2864	2	78	210	52	4		9
1996-97	5118	11	53		33	7		80

Albacore discarded, or lost, by vessel nationality:

Japanese foreign licensed

Year	number of ALB retained	discarded: released alive	discarded: dead	discarded: unknown	lost: escaped alive	lost: dead, fell off hook	lost: unknown	status unknown
1991-92	2488	1	1					2
1992-93	3037	15	67	22	3		10	8
1993-94	368		12					7
1994-95	67		9		1			1
1995-96*	0							
1996-97*	0							

Japanese chartered

Year	number of ALB retained	discarded: released alive	discarded: dead	discarded: unknown	lost: escaped alive	lost: dead, fell off hook	lost: unknown	status unknown
1991-92**	0							
1992-93	150	2	2					
1993-94	398	3	11					144
1994-95	237	2	7					5
1995-96*	0							
1996-97	1146		14		2			

New Zealand domestic

Year	number of ALB retained	discarded: released alive	discarded: dead	discarded: unknown	lost: escaped alive	lost: dead, fell off hook	lost: unknown	status unknown
1991-92	503	3	33					
1992-93**	0							
1993-94	1							
1994-95	1505	2	25					2
1995-96	2864	2	78	210	52	4		9
1996-97	3972	11	39		31	7		80

* fleet not fishing in New Zealand zone this year

** no observer data for this fleet this season

B. Summary of landing and handling status of bigeye tuna

Data are summarised from 1 October 1991 - 30 September 1997 (by fishing year). Landing and handling status codes were not recorded by observers prior to 1992.

Status of BIG	Number
Retained	363
Discarded	22
Lost	3

22 bigeye tuna were discarded:

- 10 released alive
- 11 landed dead:
  - 7 were damaged (6 by sharks, 1 by an orca)
  - 4 were recorded as discarded, but the reason is unknown
- 1 was small, it was not known if this fish was alive or dead

3 bigeye tuna were lost:

- all escaped alive

Bigeye tuna discarded, or lost, by year:

Year	number of BIG retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	77		4				
1992-93	39						
1993-94	52				1		
1994-95	87						
1995-96	37		4	1	1		
1996-97	71	10	3		1		

Bigeye tuna discarded, or lost, by vessel nationality:

Japanese foreign licensed

Year	number of BIG retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	13						
1992-93	39						
1993-94	1						
1994-95***	0						
1995-96*	0						
1996-97*	0						

Japanese chartered

Year	number of BIG retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92**	0						
1992-93***	0						
1993-94	51				1		
1994-95***	0						
1995-96*	0						
1996-97	3						

New Zealand domestic

Year	number of BIG retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	64		4				
1992-93**	0						
1993-94***	0						
1994-95	87						
1995-96	37		4	1	1		
1996-97	68	10	3		1		

* fleet not fishing in New Zealand zone this year
** no observer data for this fleet this season
*** no bigeye tuna caught (vessel was targeting southern bluefin tuna)

C. Summary of landing and handling status of southern bluefin tuna

Data are summarised from 1 October 1991 - 30 September 1997 (by fishing year). Landing and handling status codes were not recorded by observers prior to 1992.

Status of STN	Number
Retained	10374
Discarded	101
Lost	77

101 southern bluefin tuna were discarded:

- 56 were landed alive and released
- 45 were landed dead:
  - 3 were small, and discarded
  - 42 were damaged (37 by sharks, 3 by orca, 1 by a seal, 1 by propeller)

77 southern bluefin tuna lost:

- 69 escaped alive
- 5 were dead and fell off the hook at the side of the boat
- 3 were not recorded (unknown whether dead or alive)

Southern bluefin tuna discarded or lost, by year:

Year	number of STN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	546	1					
1992-93	1501	21	5				
1993-94	2852	27	9		10	1	
1994-95	2467	3	6		2	1	3
1995-96	212	4	1		6		
1996-97	2796		24		51	3	

Southern bluefin tuna discarded or lost, by vessel nationality:

Japanese foreign licensed

Year	number of STN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	542	1					
1992-93	674	2	2				
1993-94	373						
1994-95	583				2	1	2
1995-96*	0						
1996-97*	0						

Japanese chartered

Year	number of STN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92**	0						
1992-93	827	19	3				
1993-94	2479	27	9		10	1	
1994-95	1521	2	3				1
1995-96*	0						
1996-97	2331		23		40	1	

New Zealand domestic

Year	number of STN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	4						
1992-93**	0						
1993-94***	0						
1994-95	363	1	3				
1995-96	212	4	1		6		
1996-97	465		1		11	2	

* fleet not fishing in New Zealand zone this year
** no observer data for this fleet this season
*** few data (3 observed sets) and no STN caught

D. Summary of landing and handling status of yellowfin tuna

Data are summarised from 1 October 1991 - 30 September 1997 (by fishing year). Landing and handling status codes were not recorded by observers prior to 1992.

Status of YFN	Number
Retained	614
Discarded	73
Lost	1

73 yellowfin tuna were discarded:
- 59 were released alive
  - 19 were small
  - 40 were released but the reason was not specified
- 14 were landed dead:
  - 1 was small
  - 13 were damaged by sharks

1 yellowfin tuna was lost:
- it escaped alive

Yellowfin tuna discarded or lost, by year:

Year	number of YFN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	0						
1992-93	0						
1993-94	2						
1994-95	194	7	8				
1995-96	202	41	5				
1996-97	216	11	1		1		

Yellowfin tuna discarded or lost, by vessel nationality:

Japanese foreign licensed

Year	number of YFN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	0						
1992-93	0						
1993-94	0						
1994-95	0						
1995-96*	0						
1996-97*	0						

Japanese chartered

Year	number of YFN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92**	0						
1992-93	0						
1993-94	2						
1994-95	0						
1995-96*	0						
1996-97	0						

New Zealand domestic

Year	number of YFN retained	discarded			lost		
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown
1991-92	0						
1992-93**	0						
1993-94	0						
1994-95	194	7	8				
1995-96	202	41	5				
1996-97	216	11	1		1		

* fleet not fishing in New Zealand zone this year
** no observer data for this fleet this season

E. Summary of landing and handling status of swordfish

Data are summarised by fishing year from 1 October 1991 - 30 September 1997. Landing and handling status codes were not recorded by observers prior to 1992.

Status of SWO	Number
Retained	1180
Discarded	61
Lost	11
Unknown	2

61 swordfish were discarded:

21 were released alive
- 8 were small
- 3 were tagged and released
- 10 were released but the reason was not specified

32 were landed dead:
- 3 were small
- 16 were damaged by sharks
- 13 were discarded but the reason is unknown

2 were recorded as killed by the crew, then discarded
6 were discarded but the reason was not specified

11 swordfish were lost:
- 6 escaped alive
- 4 were dead and fell off the hook at the side of the boat
- 1 was not recorded (unknown whether dead or alive)

The status of 2 swordfish was unknown

no information was recorded as to whether these fish were dead or alive, or whether
they were retained or discarded

Swordfish discarded, or lost, by year:

Year	number of SWO retained	discarded			lost			status unknown
		released alive	dead	unknown	escaped alive	dead, fell off hook	unknown	
1991-92	344		9		1	1		1
1992-93	206	11	10	1				
1993-94	76		1	5				
1994-95	34	2	2					
1995-96	43	6				1		
1996-97	477	2	12		5	2	1	1

Swordfish discarded, or lost, by vessel nationality:

Japanese foreign licensed

	number	discarded			lost			
Year	of SWO retained	released alive	dead	unknown	escaped alive	dead, fell off hook	unknown	status unknown
1991-92	331		6					1
1992-93	195	11	10	1				
1993-94	36							
1994-95	0	2						
1995-96*	0							
1996-97*	0							

Japanese chartered

	number	discarded			lost			
Year	of SWO retained	released alive	dead	unknown	escaped alive	dead, fell off hook	unknown	status unknown
1991-92**	0							
1992-93	11							
1993-94	40		1	5				
1994-95	10							
1995-96*	0							
1996-97	355		11		3	1	1	

New Zealand domestic

	number	discarded			lost			
Year	of SWO retained	released alive	dead	unknown	escaped alive	dead, fell off hook	unknown	status unknown
1991-92	13		3		1	1		
1992-93**	0							
1993-94	0							
1994-95	24		2					
1995-96	43	6				1		
1996-97	122	2	1		2	1		1

* fleet not fishing in New Zealand zone this year
** no observer data for this fleet this season