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EXECUTIVE SUMMARY

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This report provides the results of a catch-per-unit-effort (CPUE) analysis for freshwater eels (*Anguilla australis*, shortfin, SFE; *A. dieffenbachii*, longfin, LFE) throughout New Zealand for the fishing years 1990–91 to 2000–01 for the eel statistical areas (ESAs) 2–3, 8–12, 17–20. These analyses update previous indices for 1990–91 to 1998–99. Catch effort data from catch effort landing returns (CELR) were extracted from the Ministry of Fisheries catch effort database, error checked, and sorted by ESA. Some adjacent ESAs were combined for the analyses because of insufficient data, resulting in four discrete datasets (ESAs 2–3 (Auckland, Hauraki), ESAs 8–12 (Rangitaiki-Wanganui, Taranaki, Manawatu, Wairarapa, Wellington), ESAs 17–19 (south Canterbury, Waitaki, Otago), and ESA 20 (Southland). Unstandardised CPUE analyses were carried out for total catch (SFE, LFE, and EEU excluding weight of bycatch) and for individual species using a CPUE index of kilograms per lift. Standardised CPUE analyses using a Generalised Linear Model (GLM) were carried out for total catch and individual species using daily catch as the response variable.

Unstandardised CPUE for total catch varied from a mean of 3.8 kg per lift in ESAs 17–19 to 12.0 kg per lift for ESAs 8–12. All regions, with the exception of ESAs 2–3 and SFE in ESAs 17–19, showed declining trends in unstandardised CPUE for total catch, and catch of SFE and LFE. Analyses of unstandardised CPUE for catches in the late 1980s suggests that CPUE has declined by about one to several kilograms per lift.

The variables permit and lifts were included in all models, and month in all models except those for ESAs 2–3. Permit (fisher) explained between 23 and 45% of the variability in CPUE and other variables were included in the model to various degrees, but their explanatory power was negligible in comparison, indicating that catch rates are very dependent on fisher experience and/or ability.

Standardised CPUE for total catch followed the same general trend as unstandardised CPUE in nearly all analyses except LFE analyses in ESAs 2–3 and 8–12. Standardised CPUE analysis for SFE in ESAs 8–12 and ESA 20 showed a marked decline in CPUE and, although in ESAs 8–12 CPUE declined markedly between 1992 and 1993, it has been reasonably stable thereafter. For ESA 20, while there is declining trend, few records and fishers were included in the SFE analysis and this is reflected in the large confidence intervals around yearly indices. For the two other regions (ESAs 2–3 and 17–19) there were no trends in SFE CPUE.

Longfin CPUE has declined in all four regions and was marked in ESAs 2–3, 8–12, and 20, and less so in ESAs 17–19. In ESAs 2–3 and 8–12 the trends have become more pronounced compared with the previous analyses.

Declines in longfin abundance are consistent with the results of the initial CPUE analyses (1991–99) and other studies indicating that longfin abundance continues to decline and this that is widespread throughout New Zealand.

1 INTRODUCTION

This report provides the results of a catch-per-unit-effort analysis (CPUE) for freshwater eels (*Anguilla australis* and *A. dieffenbachii*) for selected eel statistical areas (ESA) for the fishing years 1990–91 to 2000–01, and updates previous analyses for 1990–91 to 1998–99 (Beentjes & Bull 2002).

The commercial freshwater eel fishery developed in the 1960s with catches peaking in 1975. From 1975 to 1981 reported annual catches averaged about 2000 t, but have since declined and the average catch over the last 10 years is about 1400 t (Annala et al. 2002). The South Island eel fishery was introduced into the Quota Management System (QMS) on 1 October 2000 and Total Allowable Commercial Catches (TACC) were set for both species combined for six Quota Management Areas (QMA) (ANG 11, Nelson; ANG 12, north Canterbury; ANG 13, Te Waihora; ANG 14, south Canterbury; ANG 15, Otago/Southland; ANG 16, West coast). In the North Island, a moratorium exists on the allocation of fishing permits although there are currently no restrictions on catch.

For the successful management of any fishery it is desirable to have some index of relative abundance to monitor the effects of fishing on the population. For the South Island this could be used to adjust TACCs for each QMA. Many conventional fisheries sampling and survey techniques for determining relative abundance indices cannot validly be applied in the freshwater eel fishery, with the notable exception of CPUE analysis. Quality catch effort data are a valuable tool for monitoring trends in abundance in many marine fisheries, and for the freshwater eel fishery it may be the only index of relative abundance that can be practically and cost-effectively measured. An analysis of CPUE for all ESAs throughout New Zealand was carried out for 1990–91 to 1998–99, and indicated that abundance of longfin may be declining (Beentjes & Bull 2002). This was most apparent in ESAs 2 and 3 (Auckland, Hauraki), 8–12 (Rangitaiki-Wanganui, Taranaki, Manawatu, Wairarapa, Wellington), 17–19 (south Canterbury, Waitaki, Otago), and particularly 20 (Southland). This finding was consistent with the size and sex distributions of commercial longfin landings (Beentjes & Chisnall 1997, 1998, Beentjes 1999) and recent findings that longfins have been overfished and that this is significantly affecting recruitment (Jellyman et al. 2000, Hoyle & Jellyman 2002).

The introduction of the Catch Effort Landing Return (CELR) form in October 1989 replaced the Fisheries Statistics Unit (FSU) eel return and resulted in a few years when reporting was confused and effort was not properly recorded (Jellyman 1993). This is understandable given that the original FSU form was eel fishery specific but the CELR applies to all inshore marine fishing methods. Therefore the years before 1990–91 are unsuitable for CPUE analyses. The CELR form was replaced by an Eel Catch Effort Return (ECER) and an Eel Catch Landing Return (ECLR) on 1 October 2001. Target species is no longer required to be recorded and the generic species code EEU (unidentified) cannot be used on these new forms. The data used in the CPUE analyses presented in this report do not include data collected using the new ECER and ECLR forms because our analyses include data only up to 30 September 2001.

Before standardised CPUE analyses were undertaken (Beentjes & Bull 2002) the feasibility of conducting CPUE analyses on freshwater eels was addressed (Beentjes 1998, Beentjes & Willsman 2000), and although errors exist in the data, these could be corrected or excluded from any analysis, leaving 90% of the original data available for analysis. The experience gained from this exercise was applied to error check the data used in the current analyses.

CPUE should be provided at a level of detail that is relevant to the management and/or stock separation of the species concerned. For eels this would ideally be for each catchment area, as these represent independent fisheries (Beentjes 1998). However, catch location on CELR forms is given only by ESA (Figure 1), which includes multiple catchments. CPUE data are therefore expressed by ESA. Despite this, it is unlikely that there would be sufficient data for each catchment to satisfy the data requirements of a GLM model.

This report was carried out for the Ministry of Fisheries under Project EEL2002/02. The specific objective of the project was "To analyse CPUE trends in the commercial eel fisheries comprising Eel Statistical Areas (ESAs) 2&3 (Auckland/Hauraki), ESA 8-12 (Lower North Island), ESA 17-19 (South Canterbury/Waitaki/Otago), ESA 20 (Southland), using data up to the end of 2000/2001".

2 METHODS

2.1 Catch effort data extraction

Estimates of catch and effort for each days fishing are recorded on CELR forms (up to 1 October 2002) and these data are entered into the Ministry of Fisheries Catch Effort Database. For each daily record for 1990–91 to 2001–02, the following variables were extracted.

- Date nets were lifted
- Permit number (encoded)
- Eel statistical area (ESA)
- Number of net lifts
- Target species
- Total weight (weight of shortfin, SFE; longfin, LFE; unidentified, EEU; and bycatch)
- Weight of individual species (includes SFE, LFE, and bycatch species)

Vessel specifications were not considered relevant for the eel fishery. Permit numbers extracted from the catch effort database were anonymised by Ministry of Fisheries. Note the 1990–91 to 1998–99 data were extracted as part of the previous CPUE analyses (Beentjes & Bull 2002) and this dataset was updated by extracting data for 1999–2000 and 2000–01 fishing years, but only for ESAs 2–3, 8–12, 17–19, and 20. In this report, henceforth, fishing years are referred to by the second year, e.g., 1990–91 is referred to as 1991.

2.2 Environmental variables

Mean daily river flow data for the main rivers from each ESA were obtained from regional councils, and the NIWA hydrological database (NIWA Water Resources and Climate Archive) (Appendix A, Table A1). Moon phase was included as a possible explanatory term to account for changes in catchability with changes in the lunar cycle. The relative phase (0–1) of the moon (moon cycle) was determined for each record in the data set based on the date of each record, using an algorithm from Meeuse (1998). Both river flow and moon phase were included as predictor variables because they have been shown to affect eel catch rates (Jellyman 1991, Beentjes & Willsman 2000, Beentjes & Bull 2002). When river flow from more than one river per area was used in standardised CPUE analyses, they were treated as separate variables.

2.3 Data error checking

Catch effort data were error checked and groomed using the criteria of Beentjes & Willsman (2000). Errors were corrected where possible, or the record was deleted. Numbers of records that were corrected or deleted are shown in Table A2. Note that for 1991 to 1999 the corrections and deletions are for all ESAs (1–21) used in the CPUE analyses by Beentjes & Bull (2002). The corrections/deletions for 2000 and 2001 include data only from selected ESAs that were used in the current CPUE analyses (ESAs 2–3, 8–12, 17–19, and 20).

The variables *net lifts*, *catch*, and *area* were intensively checked as these variables have the most effect on CPUE. Corrections and deletions were made as follows.

1. Net lift errors: Records without an entry for number of nets lifted were deleted, or corrected where ancillary data such as nets in the water at midnight allowed an estimate to be made. Records with more than 100 nets were either deleted, or the correct value was found in the midnight nets column.
2. Catch weight errors: Records were deleted if there was no total weight and no weights in the species column to allow the correct values to be entered. Where species weights were present they were checked against the total weight and corrections were made where there was an obvious error. (The sum of individual species should add up to total weight: see Beentjes & Willsman (2000) for types of catch weight errors.) Records with catch weights greater than 1000 kg were also deleted.
3. Location errors: Records where location (ESA) was incorrect were generally deleted, but sometimes were corrected using information such as permit number and landing location.

2.4 Analysis of CPUE data

As in the previous eel CPUE analyses (Beentjes & Bull 2002), some ESAs were combined where there were insufficient data, and the same groupings of ESAs were retained, resulting in four discrete data sets (Table 1). Table A3 gives the number of records for each ESA data set, along with the total estimated catch, number of lifts, and the percent of records that SFE, LFE, or EEU was entered as the target species for 1990–91 to 2001–02.

Table 1: ESAs, regions, and the number of records (equivalent to the number of fisher days) for each data set used in the CPUE analyses.

ESA	Region	Records
2 and 3	Auckland and Hauraki	9 983
8, 9, 10, 11, and 12	Rangitaiki-Wanganui, Taranaki, Manawatu, Wairarapa, and Wellington	7 228
17, 18, and 19	South Canterbury, Waitaki, and Otago	8 893
20	Southland	5 785

2.4.1 Unstandardised CPUE analyses

Unstandardised CPUE analyses using raw data were carried out for the four datasets using total catch (sum of SFE, LFE, and EEU, excluding weight of bycatch), and for SFE and LFE separately. A daily index of CPUE (kg per lift) was calculated and averaged for each year.

2.4.2 Standardised CPUE analyses

Standardised CPUE analyses provide a more accurate representation of trends in CPUE because they take into account factors that can affect catch rates. Standardised analyses were conducted using total catch (SFE, LFE, and EEU excluding weight of bycatch), and for SFE and LFE catch separately. A selection criterion was applied to each dataset restricting data for analysis in three steps. First, where an individual fisher recorded less than 10 days fishing in a fishing year, the observations for that fisher in that year were excluded. Second, where an individual fisher recorded a total catch of less than 1000 kg over all years, the observations for that fisher were excluded. Third, fishers that did not land a catch in at least three years were excluded from further analysis.

Estimates of year effects and associated standard errors were obtained using a forward stepwise Generalised Linear Model (GLM) (McCullagh & Nelder 1989), with daily catch modelled as the response variable. In previous analyses (Beentjes & Bull 2002), the GLM model was fitted using daily catch per lift (kg per lift) as the response variable, but preliminary investigations suggested that the relationship between daily catch and lifts may not be linear. Using daily catch as the response variable, with lift as a possible predictor, allowed the model to consider non-linear relationships between the daily catch and lifts.

The GLM model used the log-normal transformation of positive daily catch. This implies a multiplicative model, i.e., the combined effect of two predictors is the product of their individual effects. The predictor variables used in the model were fishing year, permit number (fisher), month (season), area (ESA where more than one), river flow, and moon phase. All variables were entered into the model as categorical, except number of lifts, daily mean river flow, and moon phase, which were entered as continuous variables. The continuous variables were fitted as a 3-degree polynomial.

A stepwise regression procedure was used to fit the GLM of CPUE (daily catch) on these predictor variables. The CPUE index resulting from this procedure is termed relative year effect. The model indices are presented using a canonical form. Model fits were investigated using standard residual diagnostics, and, for each model, plots of model residuals and fitted values were investigated for evidence of departure from model assumptions. In addition, the expected catch rate resulting from the models for each of the explanatory variables fitted to the model were plotted.

The stepwise fitting method used forwards selection, i.e., began with a basic model in which the only predictor was the year, and iteratively added the best predictor until no predictors made a sufficient improvement. For all analyses, the improvement in R^2 was used as the criterion for including predictors. In the GLM model, the R^2 is defined as the proportional improvement in the residual deviance, (new deviance – old deviance) / (saturated deviance – null deviance). The predictor with the greatest improvement in R^2 was included, providing that the improvement was at least 0.005 (0.5%).

The complete data set for single eel species cannot be analysed by this method because the catch data contain zero values, as a result of which the log transformation is undefined. For these data, the analysis considered only positive catches, and zero values were ignored. Whilst zero catches can provide useful information for some fisheries, this is not so in the eel fishery. There are two reasons for this. Firstly, fishers that catch 0 kg in a day generally don't complete the CELR form. Secondly, the catch often comprises a mix of two species which fishers do not sort on the river bank/catching location before estimating the proportion weight of each species for entry into the catch effort section of the CELR – the species present in small proportions are thus likely to be recorded as zero catch and therefore are underestimated.

The inclusion of first order interaction terms was considered, but it was found that they would generally require many degrees of freedom and be impractical to estimate. This is because the fisher (permit number) was typically the most important predictor, and the large number of fishers crossed with the numbers of levels of another variable would produce a very large number of levels for the interaction term, for many of which there would be no data.

3 RESULTS

A comparison of fishers' estimated catch from CELRs with those from landing weights (catch-landing section of CELR), processors' landing weights (LFR), and export weights can be found in Beentjes & Bull (2002). The results indicated that fishers estimates of catch were consistently less than the independent landed catch figures on average by about 80% of the mean of the independent estimates for each year.

3.1 Catches and species proportions

The percentage of records where EEU was entered as the target species varied between 1% (ESA 20) to 56% (ESA 8–12) for all years combined (Table A3). The relative amounts of estimated catches that were entered as SFE, LFE, or EEU for all years combined are shown in Figure 2–Figure 5. North Island ESAs (2–3 and 8–12) had high proportions of yearly catch recorded as EEU compared to the South Island (ESAs 17–19 and 20) where it was negligible. EEU was not recorded in any ESA in the 2001 fishing year and all catches were reported by species (LFE or SFE). Shortfin reported catch was considerably greater than that of longfin in North Island ESAs 2–3, and comparable in 8–12. In contrast, longfin catch was greater in South Island ESAs 17–19 and 20.

No clear trends in total catch or for catches of individual species are apparent for the North Island regions (ESAs 2–3, and 8–12), but in the South Island (ESAs 17–19 and 20) there appears to be an overall decline in the total catch, and this is most evident for LFE (Figure 2–Figure 5).

3.1.1 CPUE analyses

The number of records, number of fishers, and catch used in standardised GLM CPUE analyses are presented in Table 2.

3.1.2 Zero catches

For all ESAs there were no zero records for total catch, which suggests that only trips where eels were caught were recorded, or there were no trips where eels were not caught. The proportion of records with zeros varied between about 10 and 95% for SFE, and 5 and 80% for LFE (Figure 6–Figure 9). Zero catches of a species can occur if the catch is recorded as unidentified (EEU) or when only one species is recorded as being caught. In the last two years, as the incidence of reporting catches as EEU has declined, so has the proportion of zero catches for each species.

3.1.3 Individual fisher effort and CPUE

The effort and mean CPUE by fishing year for each of the fishers included in the CPUE analyses for all ESAs are shown in Figure 10–Figure 13. There is clearly a wide variation among fishers in both effort expended and CPUE. About half of the fishers accounted for large amounts of both effort and catch, while a few fishers fished in only some years, with small amounts of effort and small corresponding catch.

Table 2: All data and subsets of data used in CPUE analyses, i.e., total catch, SFE, and LFE. Total catch=sum of SFE, LFE, and EEU, excluding weight of bycatch. SFE and LFE do not sum to total catch because a selection criterion was applied to each dataset restricting data for analysis (see methods).

ESA	Dataset	No. records	No. fishers	Catch (kg) in analysis
ESAs 2–3	all data	9 983	61	1 213 739
	total catch	9 244	27	1 111 926
	SFE	5 539	14	661 401
	LFE	2 381	10	145 135
ESAs 8–12	all data	7 228	50	1 318 935
	total catch	6 698	20	1 234 997
	SFE	2 889	14	425 503
	LFE	3 136	14	365 843
ESAs 17–19	all data	8 893	48	970 679
	total catch	8 107	23	870 048
	SFE	3 415	19	230 152
	LFE	6 208	21	582 026
ESA 20	all data	5 850	40	863 402
	total catch	5 359	15	784 963
	SFE	562	4	101 269
	LFE	4 541	14	630 766

3.1.4 ESAs 2 and 3 (Auckland, Hauraki)

3.1.4.1 Unstandardised CPUE analyses

CPUE for total catch fluctuated between 4.4 and 5.3 kg per lift. There are no clear trends for total catch, SFE, or LFE (Appendix A, Table A3, Figure 14).

3.1.4.2 Total catch standardised CPUE analyses

Standardised CPUE analysis for total catch (SFE, LFE, and EEU) follows the same general pattern as unstandardised CPUE with no apparent trend (Figure 14 and Figure 15). The variables permit and lifts together explained 51% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B1. Residual diagnostics suggested some evidence of departure from the model assumptions with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B1). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B2. Expected catch rates of fishers determined from the regression models ranged from about 30 to 200 kg per day, indicating a seven-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts, up to about 80 lifts. The steep rise is not significant given the wide confidence intervals.

3.1.4.3 SFE standardised CPUE analyses

Standardised CPUE analysis for SFE catch follows the same general pattern as unstandardised CPUE with no apparent trend (Figure 15). The variables permit, lifts, and moon phase explained 54% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B1. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B3). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B4. Expected catch rates of fishers determined from the regression models ranged from about 30 to

200 kg per day, indicating a seven-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts, up to about 80 lifts, and showed no strong seasonal trend, although catch rates were lowest in January and February.

3.1.4.4 LFE standardised CPUE analyses

Standardised CPUE analysis for LFE catch does not follow the same general pattern as unstandardised CPUE, and there was a clear trend of declining CPUE (Figure 15). The variables permit and lifts, together explained 47% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B1. Residual diagnostics suggested some evidence of departure from the model assumptions with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B5). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B6. Expected catch rates of fishers determined from the regression models ranged from about 20 to 200 kg per day, indicating a 10-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts, up to about 30 lifts. The steep rise after about 50 lifts is not significant given the wide confidence intervals.

Table 3: Predictor variables and R^2 values from GLM stepwise regression analysis. Variables are shown in order of acceptance by the model with associated cumulative R^2 value. Only variables entered into the model are shown.

Region	Analysis	Variable	R^2	Region	Analysis	Variable	R^2
ESAs 2–3	Total catch	fishing year	0.010	ESAs 17–19	Total catch	fishing year	0.047
		permit	0.397			permit	0.259
		lifts	0.508			lifts	0.427
						month	0.438
	SFE	fishing year	0.047		SFE	fishing year	0.045
		permit	0.444			permit	0.413
		lifts	0.530			lifts	0.481
		month	0.536			month	0.488
	LFE	fishing year	0.023		LFE	fishing year	0.038
		permit	0.452			permit	0.301
		lifts	0.467			lifts	0.451
						month	0.471
ESAs 8–12	Total catch	fishing year	0.057	ESA 20	Total catch	fishing year	0.025
		permit	0.426			permit	0.254
		lifts	0.487			lifts	0.450
		month	0.515			month	0.470
	SFE	fishing year	0.117		SFE	fishing year	0.097
		permit	0.418			permit	0.367
		lifts	0.457			lifts	0.541
		month	0.489			month	0.553
		area	0.496			Mataura R.	0.559
	LFE	fishing year	0.040		LFE	fishing year	0.021
		permit	0.371			permit	0.236
		lifts	0.431			lifts	0.446
		month	0.447			month	0.471
		area	0.458				

3.1.5 ESAs 8–12 (Rangitaiki-Wanganui, Taranaki, Manawatu, Wairarapa, Wellington)

3.1.5.1 Unstandardised CPUE analyses

CPUE for total catch fluctuated between 5.2 and 12 kg per lift. There appears to be a general trend of declining CPUE for total catch, SFE, and to a lesser extent for LFE (Appendix A, Table A3, Figure 16).

3.1.5.2 Total catch standardised CPUE analyses

Standardised CPUE analysis for total catch (SFE, LFE, and EEU) follows the same general pattern as unstandardised CPUE with a trend of declining CPUE (Figure 16 and Figure 17). The variables permit, lifts, and month together explained 51% of the variation in CPUE and were included in the model (Table 3). Standardised indices 95% confidence intervals are shown in Table B2. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B7). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B8. Expected catch rates of fishers determined from the regression models ranged from about 30 to 200 kg per day, indicating a seven-fold range in expected catch rates. Catch was reasonably proportional to the number of lifts, up to about 40 lifts. The steep rise after about 80 lifts is not significant given the wide confidence intervals. There was a strong seasonal trend in catch rates, which were lower in the winter months.

3.1.5.3 SFE standardised CPUE analyses

Standardised CPUE analysis for SFE catch follows the same general pattern as unstandardised CPUE with a very large decline in CPUE after 1992 after which it was reasonably stable (Figure 17). The variables permit, lifts, month, and area, explained 50% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B2. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B9). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B10. Expected catch rates of fishers determined from the regression models ranged from about 30 to 200 kg per day, indicating a seven-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts, up to about 50 lifts before sharply declining; this decline is not significant given the wide confidence intervals. There was also a strong seasonal trend in catch rates, which were lowest in the winter and highest in spring-summer. Expected catch rates were also low for ESA 12 and similar for other ESAs.

3.1.5.4 LFE standardised CPUE analyses

Standardised CPUE analysis for LFE catch does not follow the same general pattern as unstandardised CPUE and there was a clear trend of declining CPUE (Figure 17). The variables permit, lifts, month, and area, explained 46% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B2. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B11). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B12. Expected catch rates of fishers determined from the regression models ranged from about 30 to 200 kg per day, indicating a seven-fold range in expected catch rates. Catch was reasonably proportional to the number of lifts up to about 40 lifts. The steep rise after about 80 lifts is not significant given the wide confidence intervals. There was also a strong seasonal trend in catch rates, which were low in the winter months. Expected catch rates were also high for ESA 12 and similar for other ESAs.

3.1.6 ESAs 17–19 (South Canterbury, Waitaki, Otago)

3.1.6.1 Unstandardised CPUE analyses

CPUE for total catch fluctuated between 3.8 and 6.8 kg per lift. There was a general decline in CPUE for total catch and LFE up until 1995, thereafter stabilising (Appendix A, Table A3, Figure 18). There was no trend in SFE CPUE.

3.1.6.2 Total catch standardised CPUE analyses

Standardised CPUE analysis for total catch (SFE, LFE, and EEU) follows the same general pattern as unstandardised CPUE, but differs over the last two years with a trend of increasing CPUE (Figure 18 and Figure 19). Overall there appears to be no trend. The variables permit (fisher), lifts, and month, together explained 44% of the variation in CPUE and were included in the model (Table 3). Standardised indices, and 95% confidence intervals are shown in Table B3. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B13). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Figure B14. Expected catch rates of fishers determined from the regression models ranged from about 40 to 170 kg per day indicating, a four-fold range in expected catch rates. Catch appeared to be proportional to the number of lifts up to about 40 lifts. There was also a seasonal trend in catch rates, which were high in summer and spring; catch rates appear high for winter, but there was little catch and variance was high.

3.1.6.3 SFE standardised CPUE analyses

Standardised CPUE analysis for SFE catch differs from the unstandardised CPUE in that the initial decline in standardised CPUE between 1991 and 1993 is more marked, and overall CPUE has increased since 1995 except in 1999 (Figure 19). The variables permit, lifts, and month, explained 49% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B3. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B15). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B16. Expected catch rates of fishers determined from the regression models ranged from about 20 to 200 kg per day, indicating a ten-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts and showed a seasonal trend of declining catches in winter although error bars are wide and the difference is probably not significant.

3.1.6.4 LFE standardised CPUE analyses

Standardised CPUE analysis for LFE catch follows the same general pattern as unstandardised CPUE with a clear trend of declining CPUE between 1991 and 1995, after which it has increased slightly and then stabilised (Figure 19). The variables permit, lifts, month, and area, together explained 47% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B3. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B17). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B18. Expected catch rates of fishers determined from the regression models ranged from about 30 to 170 kg per day, indicating a six-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts, up to 50 lifts. Catch rates showed a seasonal trend of low catches in spring and highest catches in summer.

3.1.7 ESA 20 (Southland)

3.1.7.1 Unstandardised CPUE analyses

CPUE for total catch fluctuated between 4.6 and 9.7 kg per lift. There was a sharp decline in total catch CPUE between 1991 and 1993, followed by a marked increase in 1994 and then a period of relatively stable catches until 2001 (Appendix A, Table A3, Figure 20); LFE CPUE followed a similar trend but without a peak in 1994. CPUE for SFE declined markedly between 1991 and 1993 followed by a marked increase in 1994, a period of stability between 1995 and 2000, and then a sharp decline in 2001.

3.1.7.2 Total catch standardised CPUE analyses

Standardised CPUE analysis for total catch (SFE, LFE, and EEU) follows the same general pattern of declining CPUE as the unstandardised analysis, although the decline is more marked (Figure 20 and Figure 21). The variables permit (fisher), lifts, and month, together explained 47% of the variation in CPUE (Table 3). Standardised indices and 95% confidence intervals are shown in Table B4. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B19). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B20. Expected catch rates of fishers determined from the regression models ranged from about 50 to 250 kg per day, indicating a five-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts up to about 80 lifts. Catch rates showed a seasonal trend of high catches in summer and spring; catch rates appear high for winter but there was little catch and variance was high.

3.1.7.3 SFE standardised CPUE analyses

Standardised CPUE analysis for SFE follows the same trend of declining CPUE as unstandardised analysis. Note that compared with other analyses, few records and fishers were included in the SFE analysis (see Table 2) and this is reflected in the large confidence intervals around yearly indices (Figure 21). The variables permit, lifts, and month, together explained 56% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B4. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B21). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B22. Expected catch rates of fishers determined from the regression models ranged from about 50 to 200 kg per day, indicating a four-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts up to about 40 lifts. Catch rates showed a seasonal trend of high catches in summer and spring and increased with Mataura River flow up to 30 cumecs, declining thereafter.

3.1.7.4 LFE standardised CPUE analyses

Standardised CPUE analysis for LFE catch follows the same general pattern as unstandardised CPUE with a clear trend of declining CPUE, although the decline is more marked and in the last two years CPUE has increased slightly (Figure 21). The variables permit, lifts, and month, together explained 47% of the variation in CPUE and were included in the model (Table 3). Standardised indices and 95% confidence intervals are shown in Table B4. Residual diagnostics suggested some evidence of departure from the model assumptions, with the distributions of residuals suggesting departure from the assumptions of normality (Appendix B, Figure B23). Plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendix B, Figure B24. Expected catch rates of fishers determined from the regression models ranged from about 50 to 250 kg per day, indicating a five-fold range in expected catch rates. Catch appeared reasonably proportional to the number of lifts up to about 80 lifts. Catch rates showed a seasonal trend of high catches in summer and spring; catch rates appear high for winter, but there was little catch and variance was high.

4 DISCUSSION

This report presents updated CPUE analyses for the commercial freshwater eel fishery for four discrete regions (ESAs 2–3, 8–12, 17–19, and 20). The initial analyses included ESAs for the entire country for 1991 to 1999 (Beentjes & Bull 2002), and only those areas that showed declines in CPUE were updated and included in the current analyses.

4.1 Catch and species distribution

No detailed descriptive analysis of catch and species composition throughout the country was undertaken as this was thoroughly covered as part of the initial CPUE analyses (Beentjes & Bull 2002) and will only be summarised here.

ESAs throughout New Zealand support both shortfin and longfin catches, but the North Island is predominantly shortfin and the South Island longfin. This is consistent with the results of commercial catch sampling between 1996 and 1998 (Beentjes & Chisnall 1997, 1998, Beentjes 1999, Chisnall & Kemp 2000). Exceptions include the shortfin fisheries in Te Waihora and Lake Brunner, and the northeast of the South Island (ESAs 14 and 16, Marlborough and North Canterbury).

The proportion of the national catch contributed by ESA is unchanged since the 1980s and the key areas are Northland, Waikato, Southland, and Te Waihora. The proportion of eels reported as unidentified (EEU) increased dramatically after the introduction of the CELR form in 1989. The degree to which LFE or SFE, rather than EEU, was recorded by fishers varied between regions. In general, a high proportion of the catch was recorded by species where one species was dominant, e.g., ESA 20 and Te Waihora. In these ESAs, catches are predominantly longfin or shortfin respectively, compared to other areas where a mixture of both species makes it more difficult for fishers to estimate the true proportion.

The introduction of South Island freshwater eels into the Quota Management System in October 2000 has required fishers to be more diligent in completing the CELR form and has seen an improvement in quality of catch effort data. Indeed, there were no records of EEU being used in the 2000–01 fishing year with all catches being identified to species (see Figure 2–Figure 5). In addition, replacement of the CELR form with the ECER and ECLR on 1 October 2001 should help to improve the quality of catch effort data and thereby future CPUE analyses.

4.2 Catch used in analysis

In the previous analyses from 1991 to 1999, fishers' estimates of daily catch were about 80% of independent catch figures (export, CELR catch landing, and processors'), except for Te Waihora where the figure was about 67% of the previous estimates (Beentjes & Bull 2002). The shortfall in fishers' estimates of catch compared to independent estimates is assumed to be a result of fishers' underestimating catch when completing the catch effort section of the CELR. This contrasts with other species where the proportion of actual landings included in CPUE analyses is often dependent on the target species selected and whether the species is one of the top five caught (Beentjes 2000). The CELR form provides fields for five only species and entry is in order of decreasing weight. In the eel fishery only two species (SFE and LFE) are caught in any abundance and these will always be included on the CELR.

4.3 Unstandardised CPUE

The updated unstandardised CPUE included analyses for individual species as well as total catch analyses, highlighting trends that may have been masked by the combined analyses. Unstandardised CPUE for total catch varied from a mean of 3.8 kg per lift in ESAs 17–19 (south Canterbury, Waitaki, Otago) to 12.0 kg per lift for ESAs 8–12 (Rangitaiki-Wanganui, Taranaki, Manawatu, Wairarapa, Wellington) (see Appendix A, Table A3). All regions, except of ESAs 2–3, showed declining trends in unstandardised CPUE for total catch, SFE, and LFE, though the SFE trend in 17–19 is much less pronounced than in ESAs 8–12 and 20. Analyses of unstandardised CPUE by Jellyman (1994) for catches in the late 1980s suggests that CPUE has declined by about one to several kilograms per lift.

4.4 Standardised CPUE

The statistical method employed in the current CPUE analyses used a GLM stepwise regression approach, as did Beentjes & Bull (2002), but some changes to the analysis were introduced. These included entering lifts as a predictor variable and not part of the response variable, removing zero records from the analyses, using R^2 rather than Akaike's information criterion (AIC) for individual species analyses, applying different data restriction criteria, and allowing all months into the model regardless of catches. By virtue of these revisions to the models the relative indices may have changed slightly, but overall the trends in the indices were similar to those from the previous analyses for the same period (1991–99). However, errors in the catch-effort data may remain, and it is unknown how such errors will affect the resulting indices.

Standardised CPUE analyses using the GLM model accounted for the effects that variables fisher (permit), season (month), area (ESA), moon phase, and river flow may have had on catch rates. The variables permit and lifts were included in all models, and month in all models except those for ESAs 2–3 (Table 3). In ESAs 2–3, fishing can take place all year round and we would not expect such a strong seasonal affect. The finding that month was an important variable affecting catch rates in the southern ESAs is understandable since water temperature varies seasonally and eel catch rates are related to water temperature (Jellyman 1991, 1997). Fisher explained between 23 and 45% of the variability in CPUE and other variables were included in the model to various degrees, but their explanatory power was negligible in comparison. This indicates that catch rates are very dependent on fisher experience and/or ability. The regression models presented here ignore zero catches, a consequence of the GLM modelling approach used. Better methods of modelling catch-effort data with zero catches may assist in better determining standardised CPUE indices, but these have yet to be developed.

Apart from ESA, we know nothing about catch location, only the effort involved in maintaining catches. In the interpretation of the results we assume that fishers are not travelling to increasingly remote areas to maintain catch rates. For many areas we know from speaking with fishers and processors that our assumption is valid.

Standardised CPUE for total catch followed the same general trend as unstandardised CPUE in nearly all analyses, except LFE analyses in ESAs 2–3 and 8–12. In these cases the inclusion of predictor variables in the model have resulted in a different trend. Interpretation of total catch (SFE, LFE, and EEU) CPUE trends is complicated because CPUE analyses for shortfin and longfin individually sometimes resulted in very different trends in the data. For example, in ESAs 2–3 (Auckland, Hauraki) there was no apparent trend in total catch CPUE, but both SFE and LFE CPUE are declining, the latter markedly (see Figure 8). In this case the longfin data had little effect on the total catch CPUE because catches were small compared to those of shortfin. It was for this reason that it was necessary to conduct standardised CPUE analyses on individual species, despite the data limitations for some areas/species and the problems with fishers identifying their catch to species. If catch effort analyses are to be useful for assessing sustainability of eel stocks, it is essential that shortfin and longfin be analysed separately. The introduction of the new eel fishery catch effort form in October 2001 may contribute to improved quality of data.

This is the first standardised CPUE analysis attempted for SFE in ESAs 8–12 and ESA 20 and in both the these regions there were marked declines in CPUE (see Figure 17 and Figure 21). For ESAs 8–12, although CPUE declined markedly between 1992 and 1993 it has been reasonably stable thereafter. For ESA 20, although there is a declining trend, few records and fishers were included in the SFE analysis (see Table 2) and this is reflected in the large confidence intervals around yearly indices. For the two other regions (ESAs 2–3 and 17–19) there were no consistent trends in SFE CPUE (see Figure 15 and Figure 19).

Longfin CPUE declined for all four regions and was marked in ESAs 2–3, 8–12, and 20, (see Figure 15, Figure 17, and Figure 21) and less so in ESAs 17–19 (see Figure 19). In ESAs 2–3 and 8–12 the trend has become more pronounced, and in ESA 20 a slight increase in CPUE in 2000 fishing year has reduced the negative slope of the trend slightly. We have no explanation for the increase in CPUE in 2000.

4.5 Conclusions

The observed declines in longfin abundance are consistent with the results of the initial CPUE analyses (1991–99), indicating that longfin abundance has declined and that this is widespread throughout New Zealand. This is consistent with the conjecture by Jellyman et al. (2000) and Hoyle & Jellyman (2002) that longfins are being overfished and that such overfishing has significantly affected recruitment. Additionally, the length frequency distributions determined from the catch sampling programme indicate that longfin eels may be more heavily exploited than shortfin (Beentjes & Chisnall 1997, 1998, Beentjes 1999). However, without adequate-understanding of the stock status and biological parameters such as the stock-recruitment relationship for eels, it is not possible to draw any firm conclusions.

5 ACKNOWLEDGMENTS

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6 REFERENCES

Annala, J.H.; Sullivan, K.J.; O'Brien, C.J.; Smith, N.W.M.; Varian, S.J.A. (2002). Report from the Fishery Assessment Plenary, May 2002: stock assessments and yield estimates. 640 p. (Unpublished report held in NIWA library, Wellington.)

Beentjes, M.P. (1998). A revised catch and effort form for the commercial freshwater eel fishery. Final Research Report for Ministry of Fisheries Research Project EEL9701. 21 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Beentjes, M.P. (1999). Size, age, and species composition of South Island commercial eel catches from market sampling (1997–98). *NIWA Technical Report 51.* 51 p.

Beentjes, M.P. (2000). Assessment of red cod stocks for (RCO3 and RCO 7) for 1999. *New Zealand Fisheries Assessment Report 2000/25.* 78 p.

Beentjes, M.P.; Bull, B. (2002). CPUE analyses of the commercial freshwater eel fishery. *New Zealand Fisheries Assessment Report 2002/18.* 55 p.

Beentjes, M.P.; Chisnall, B.L. (1997). Trends in size and species composition and distribution of commercial eel catches. *New Zealand Fisheries Data Report 89.* 71 p.

Beentjes, M.P.; Chisnall, B.L. (1998). Size, age, and species composition of commercial eel catches from market sampling (1996-97). *NIWA Technical Report 29.* 124 p.

Beentjes, M.P.; Willsman, A. (2000). Feasibility study of CPUE data for the eel fishery. Final Research Report for Ministry of Fisheries Research Project MOF804I. 20 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Chisnall, B.L.; Kemp, C. (2000). Size, age, and species composition of commercial eel catches from market sampling in the North Island. *NIWA Technical Report 87.* 67 p.

Hoyle, S.D.; Jellyman, D.J. (2002). Longfin eels need reserves: modelling the impacts of commercial harvest on stocks of New Zealand eels. *Marine and Freshwater Research 53*: 1–9.

Jellyman, D.J. (1991). Factors affecting the activity of two species of eel (*Anguilla* spp.) in a small New Zealand lake. *Journal of Fish Biology 39*: 7–14.

Jellyman, D.J. (1993). A review of the fishery for freshwater eels in New Zealand. *New Zealand Freshwater Fisheries Report 10.* 51 p.

Jellyman, D.J. (1994). The fishery for freshwater eels (*Anguilla* spp.) in New Zealand. New Zealand Fisheries Assessment Research Document 94/14. 24 p. (Unpublished report held in NIWA library, Wellington.)

Jellyman, D.J. (1997). Variability in growth rates of freshwater eels (*Anguilla* spp.) in New Zealand. *Ecology of Freshwater Fish 6*: 108–115.

Jellyman, D.J.; Graynoth, E.; Francis, R.I.C.C.; Chisnall, B.L.; Beentjes, M.P. (2000). A review of evidence for a decline in the abundance of longfinned eels (*Anguilla dieffenbachii*) in New Zealand. Final Research Report for Ministry of Fisheries Research Project EEL9802. (Unpublished Report held by Ministry of Fisheries, Wellington.)

McCullagh, P.; Nelder, J.A. (1989). Generalised linear models. Chapman & Hall, London.

Meeuse, J. (1998). Astronomical algorithms. 2nd Edition.Willmann-Bell: Richmond, VA, 476 p.

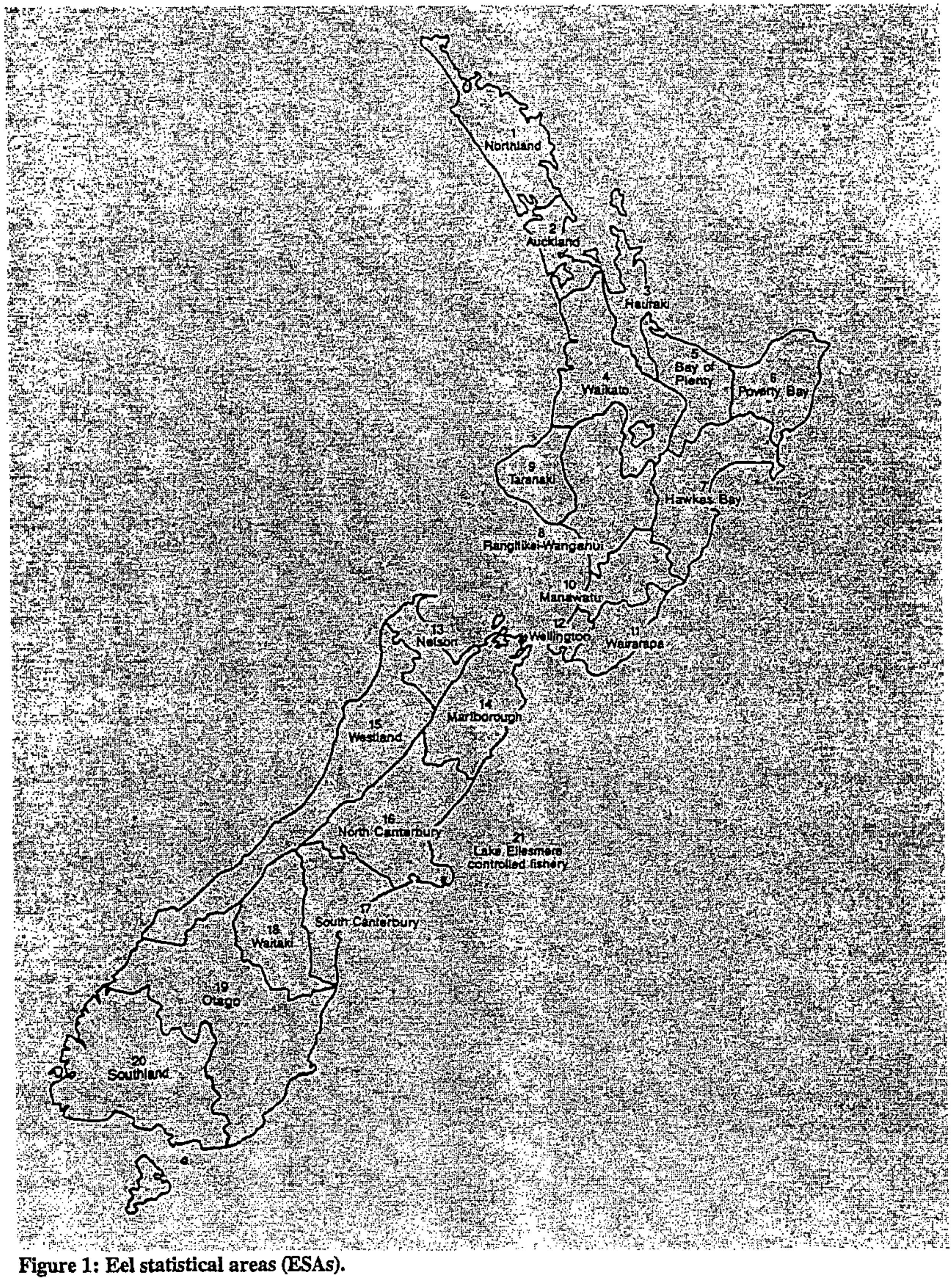

Figure 1: Eel statistical areas (ESAs).

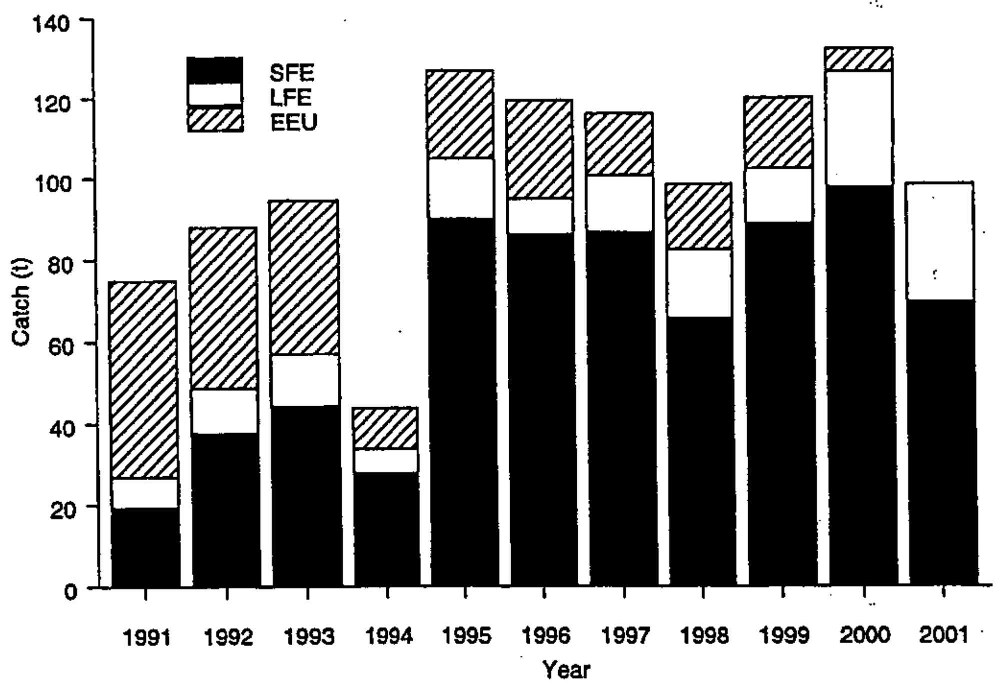

Figure 2: Total catch of SFE, LFE, and unclassified eel catch (EEU) in ESAs 2–3 for the years 1990–91 to 2001–02. Overall 75 % of catch was identified to species.

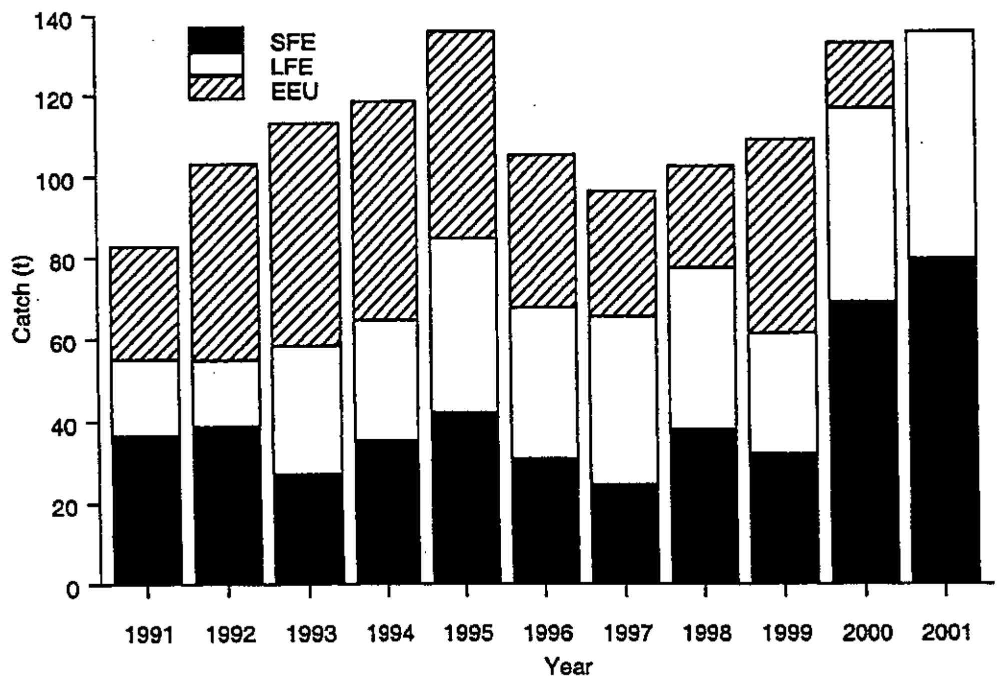

Figure 3: Total catch of SFE, LFE, and unclassified eel catch (EEU) in ESAs 8–12 for the years 1990–91 to 2001–02. Overall 68 % of catch was identified to species.

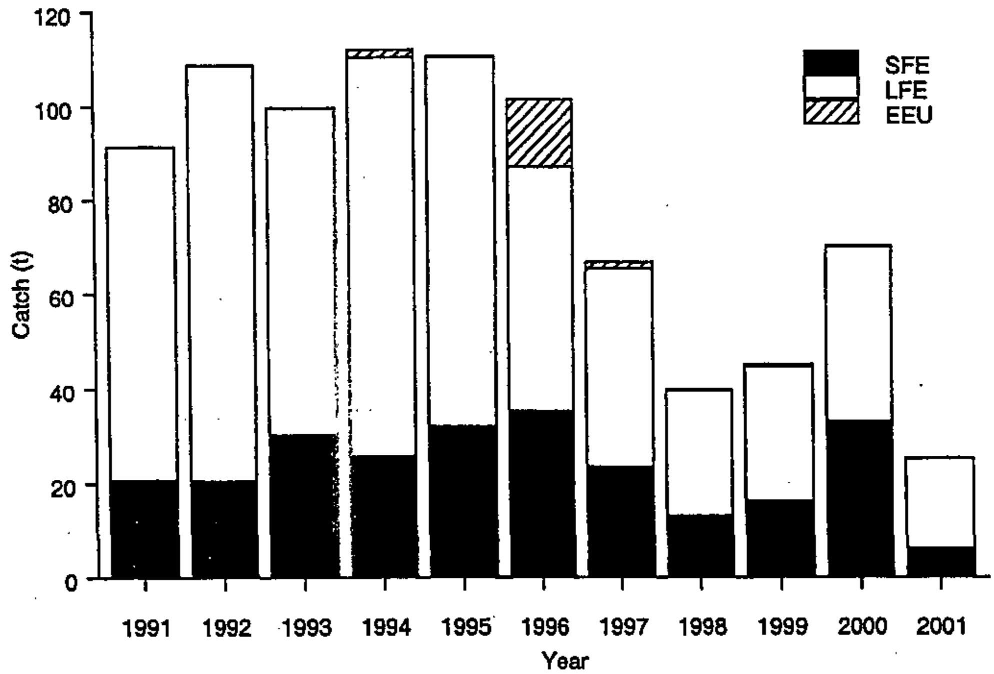

Figure 4: Total catch of SFE, LFE, and unclassified eel catch (EEU) in ESAs 17–19 for the years 1990–91 to 2001–02. Overall 98% of catch was identified to species.

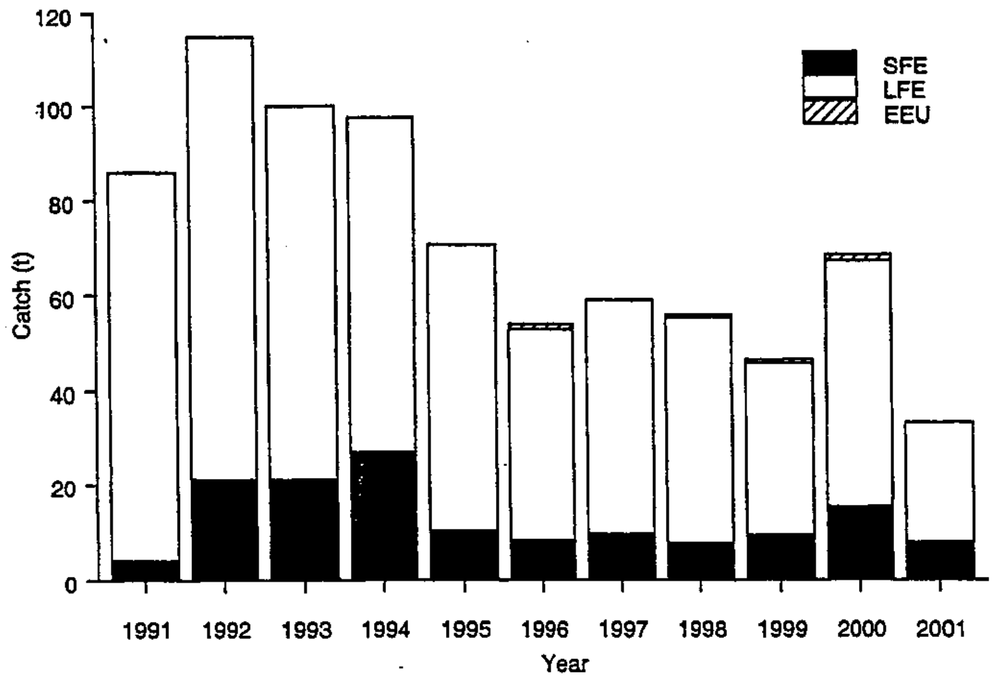

Figure 5: Total catch of SFE, LFE, and unclassified eel catch (EEU) in ESA 20 for the years 1990–91 to 2001–02. Overall 99% of catch was identified to species.

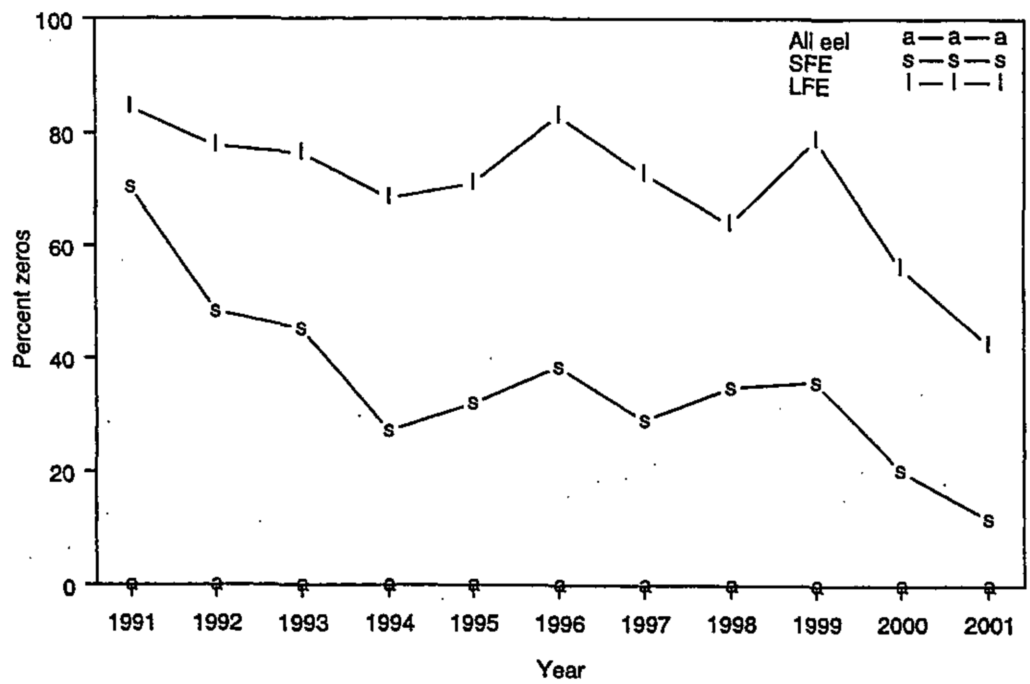

Figure 6: Proportion of zero records for (a) all eel catch, (b) SFE catch, and (c) LFE catch in ESAs 2–3 for the years 1990–91 to 2001–02.

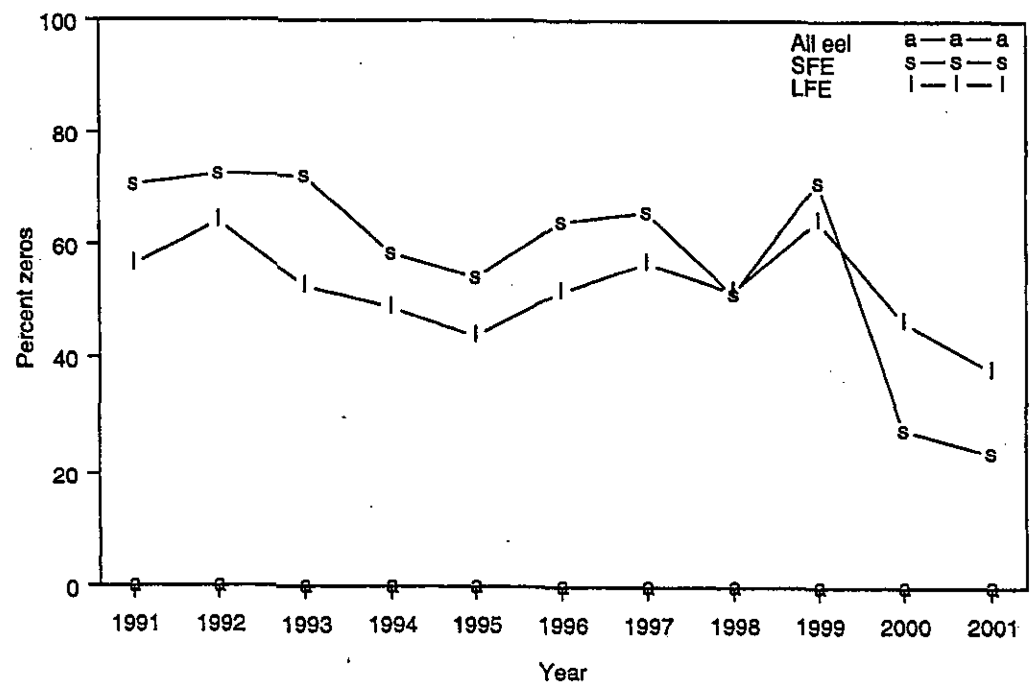

Figure 7: Proportion of zero records for (a) all eel catch, (b) SFE catch, and (c) LFE catch in ESAs 8–12 for the years 1990–91 to 2001–02.

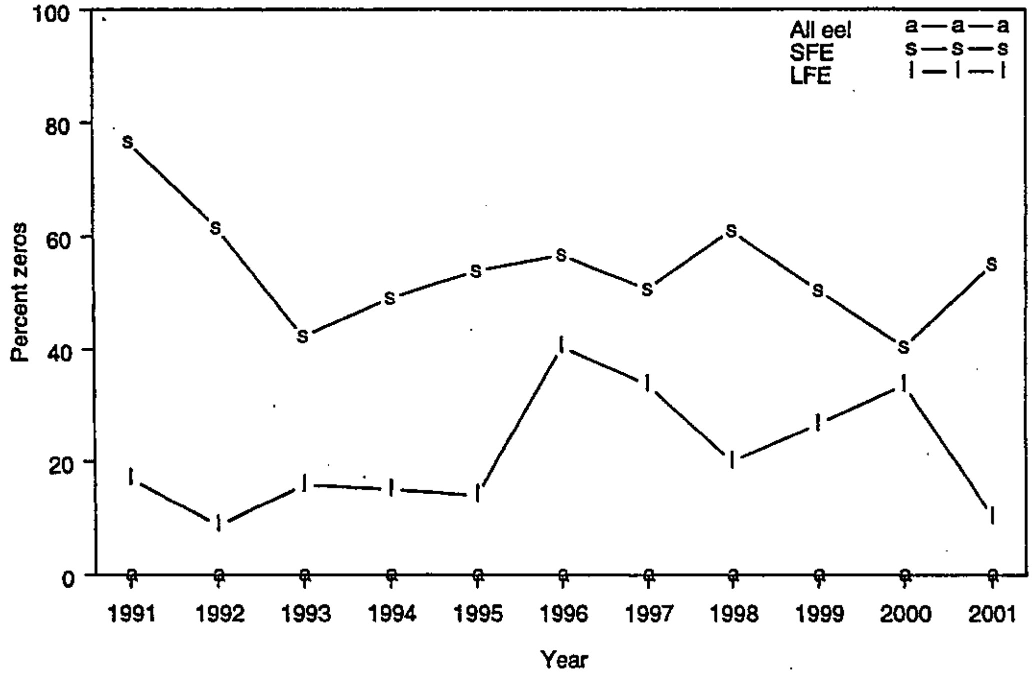

Figure 8: Proportion of zero records for (a) all eel catch, (b) SFE catch, and (c) LFE catch in ESAs 17–19 for the years 1990–91 to 2001–02.

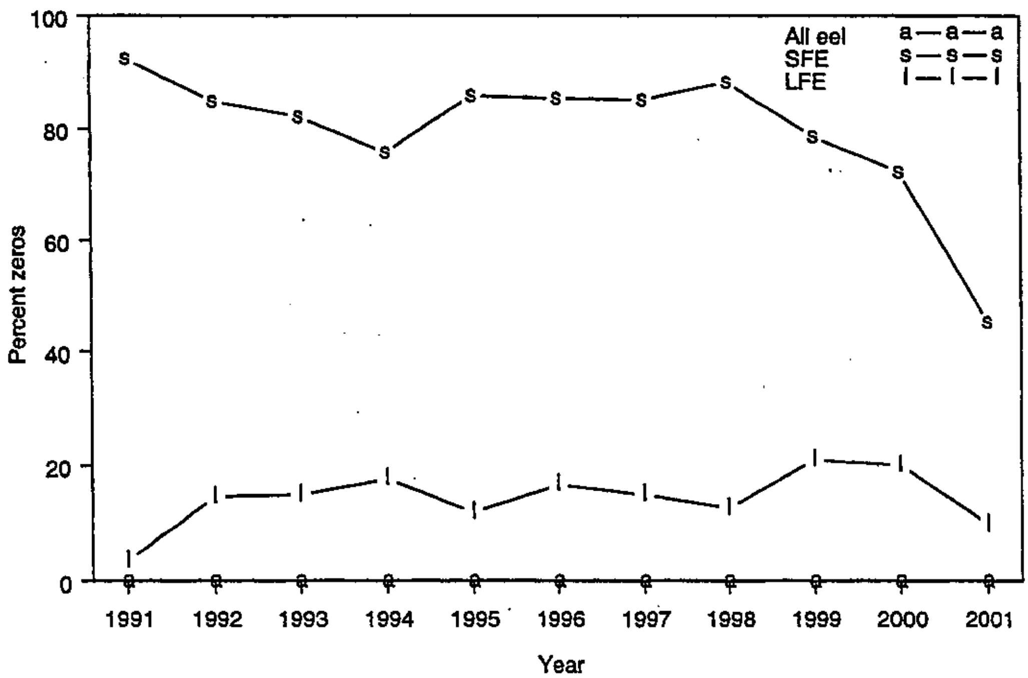

Figure 9: Proportion of zero records for (a) all eel catch, (b) SFE catch, and (c) LFE catch in ESA 20 for the years 1990–91 to 2001–02.

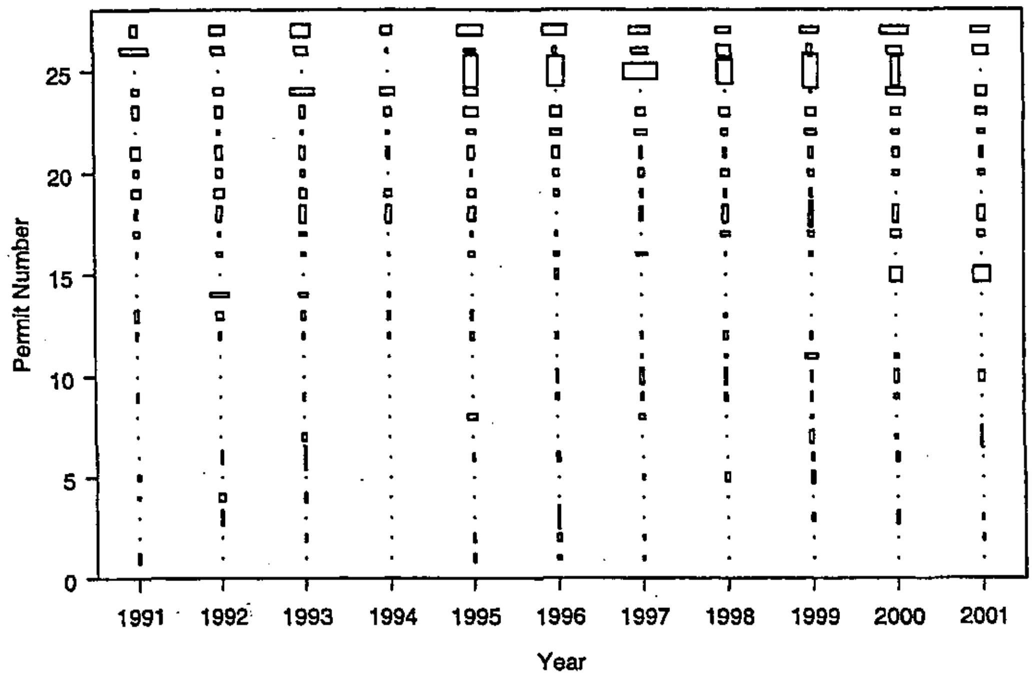

Figure 10: Annual effort and mean CPUE for each eel fisher in ESAs 2–3, by year, for the years 1990–91 to 2001–02. Horizontal dimension of each rectangle indicates the amount of effort while the vertical dimension indicates the catch per unit effort in each year (zero entries are indicated by ".").

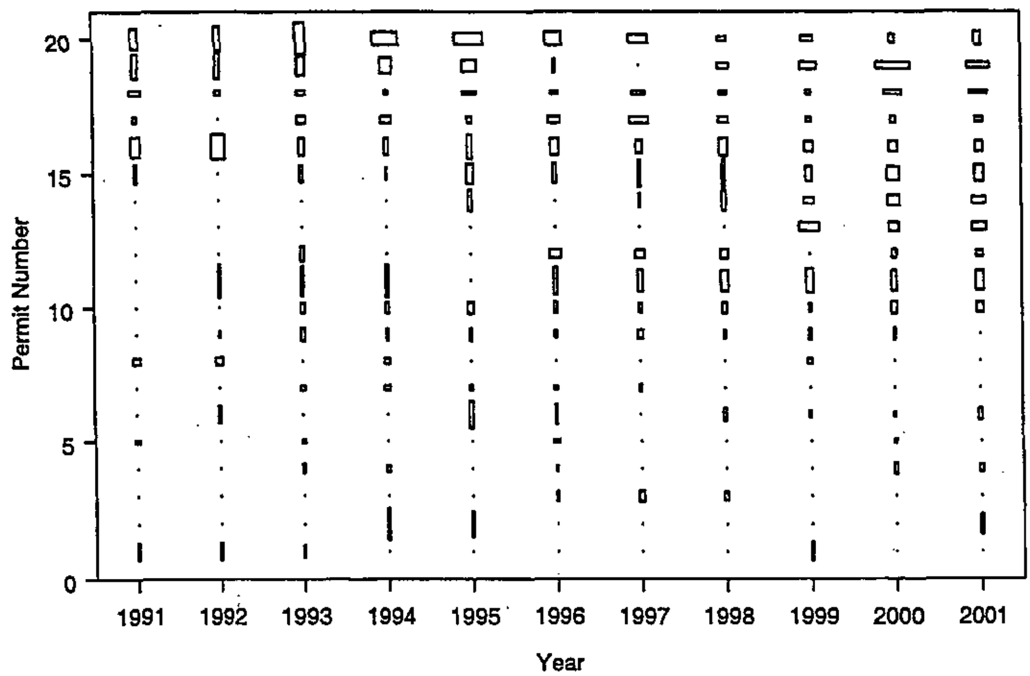

Figure 11: Annual effort and mean CPUE for each eel fisher, in ESAs 8–12, by year, for the years 1990–91 to 2001–02. Horizontal dimension of each rectangle indicates the amount of effort while the vertical dimension indicates the catch per unit effort in each year.

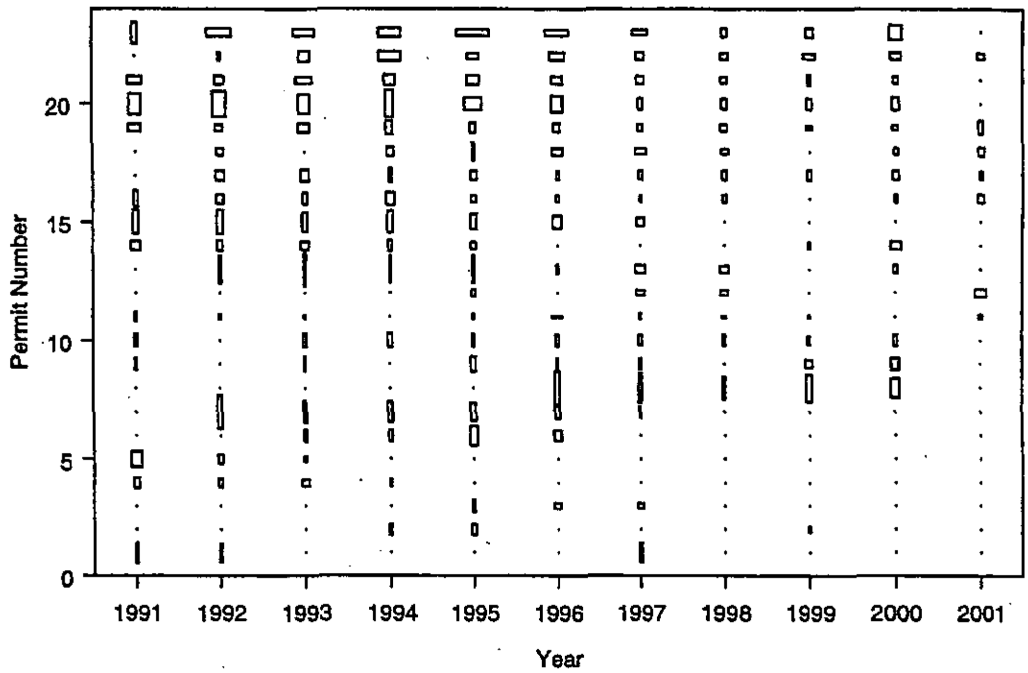

Figure 12: Annual effort and mean CPUE for each eel fisher, in ESAs 17 –19, by year, for the years 1990–91 to 2001–02. Horizontal dimension of each rectangle indicates the amount of effort while the vertical dimension indicates the catch per unit effort in each year.

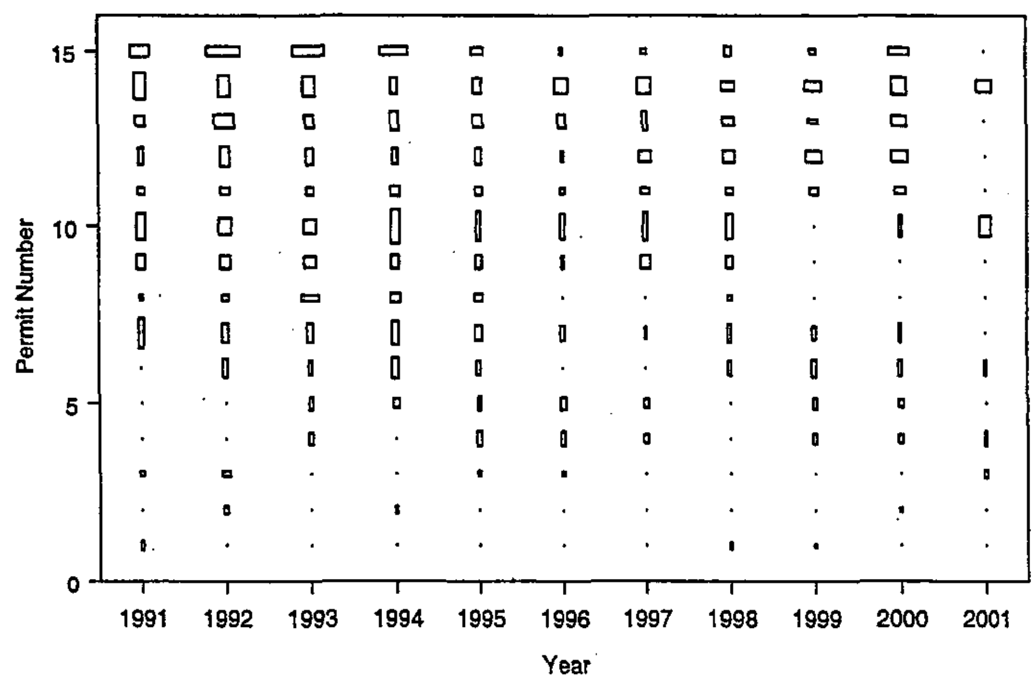

Figure 13: Annual effort and mean CPUE for each eel fisher, for ESA 20, by year, for the years 1990–91 to 2001–02. Horizontal dimension of each rectangle indicates the amount of effort while the vertical dimension indicates the catch per unit effort in each year.

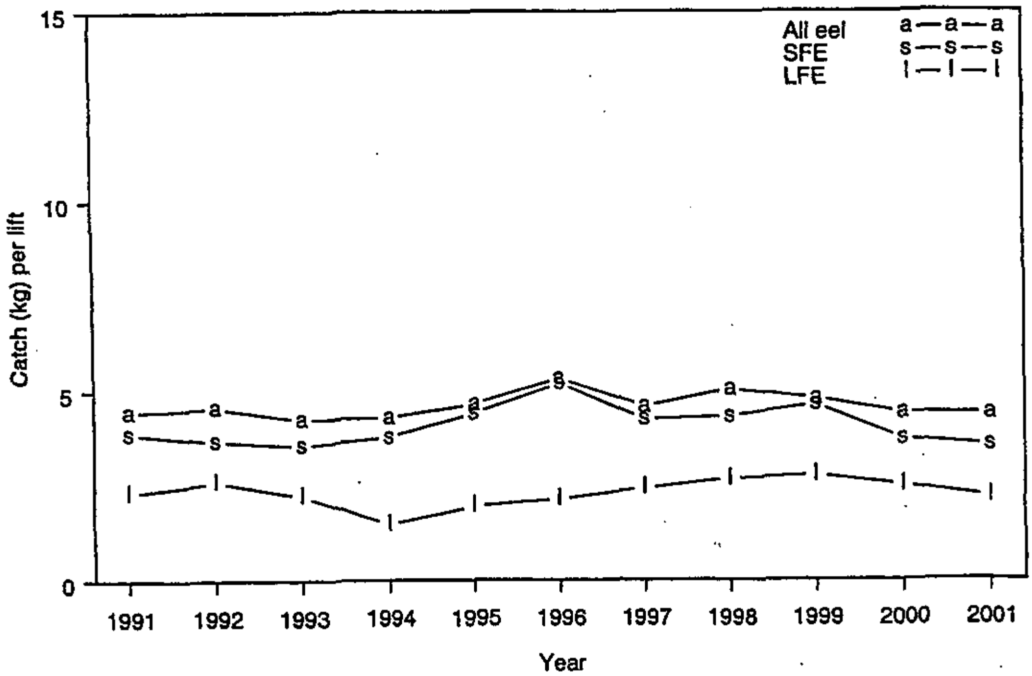

Figure 14: Unstandardised catch per lift (kg per lift) for SFE, LFE, and all eel catch in ESAs 2–3 for the years 1990–91 to 2001–02.

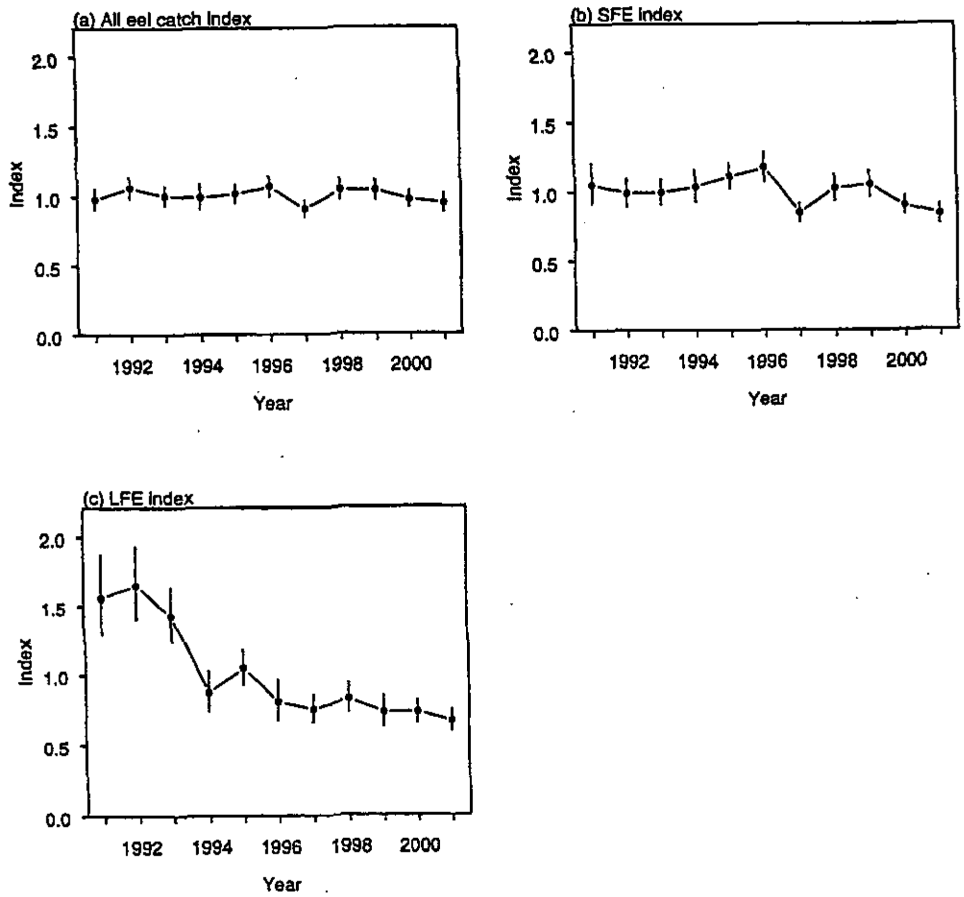

Figure 15: Standardised catch rate (catch per day) CPUE indices for (a) all eel catch, (b) SFE, and (c) LFE in ESAs 2–3 for the years 1990–91 to 2001–02.

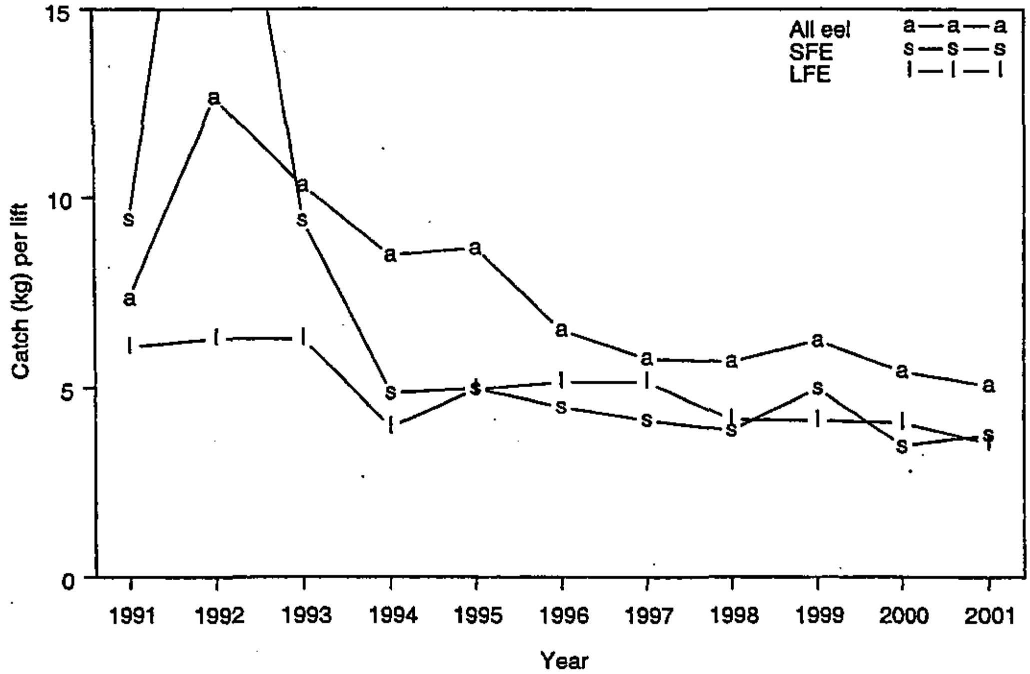

Figure 16: Unstandardised catch per lift (kg per lift) for SFE, LFE, and all eel catch in ESAs 8–12 for the years 1990–91 to 2001–02.

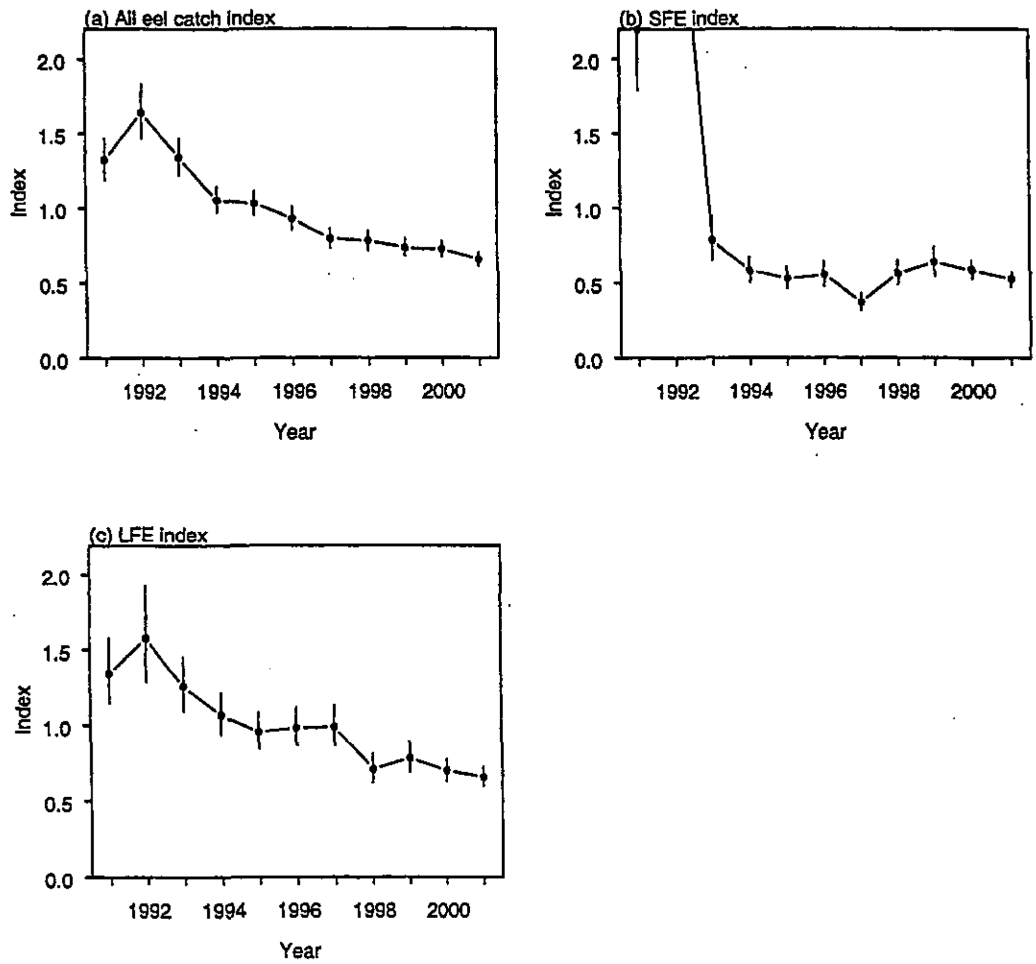

Figure 17: Standardised catch rate (catch per day) CPUE indices for (a) all eel catch, (b) SFE, and (c) LFE in ESAs 8–12 for the years 1990–91 to 2001–02.

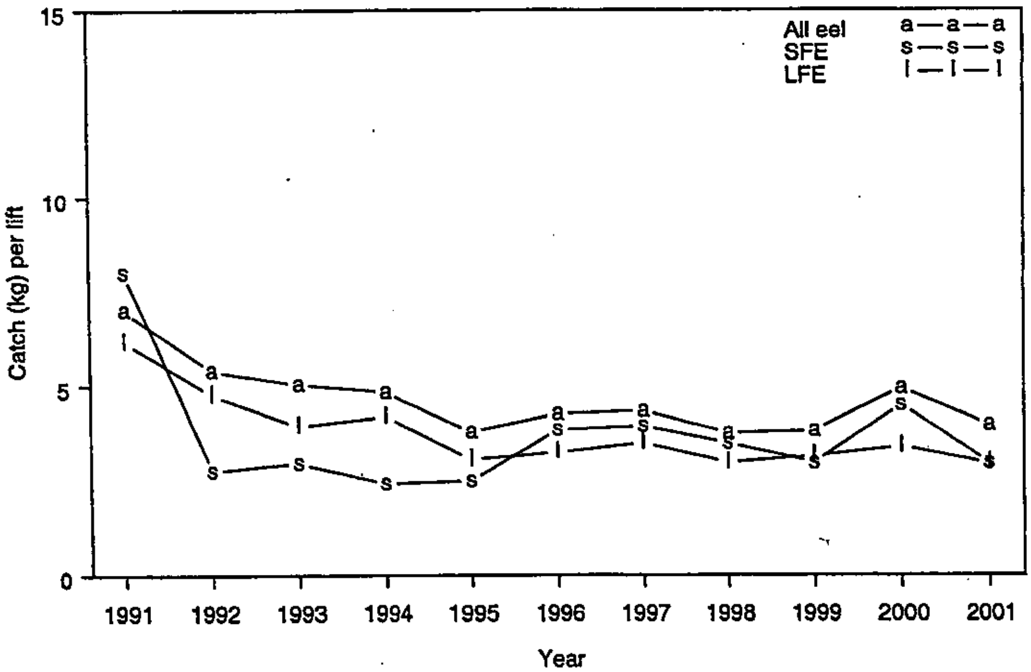

Figure 18: Unstandardised catch per lift (kg per lift) for SFE, LFE, and all eel catch in ESAs 17–19 for the years 1990–91 to 2001–02.

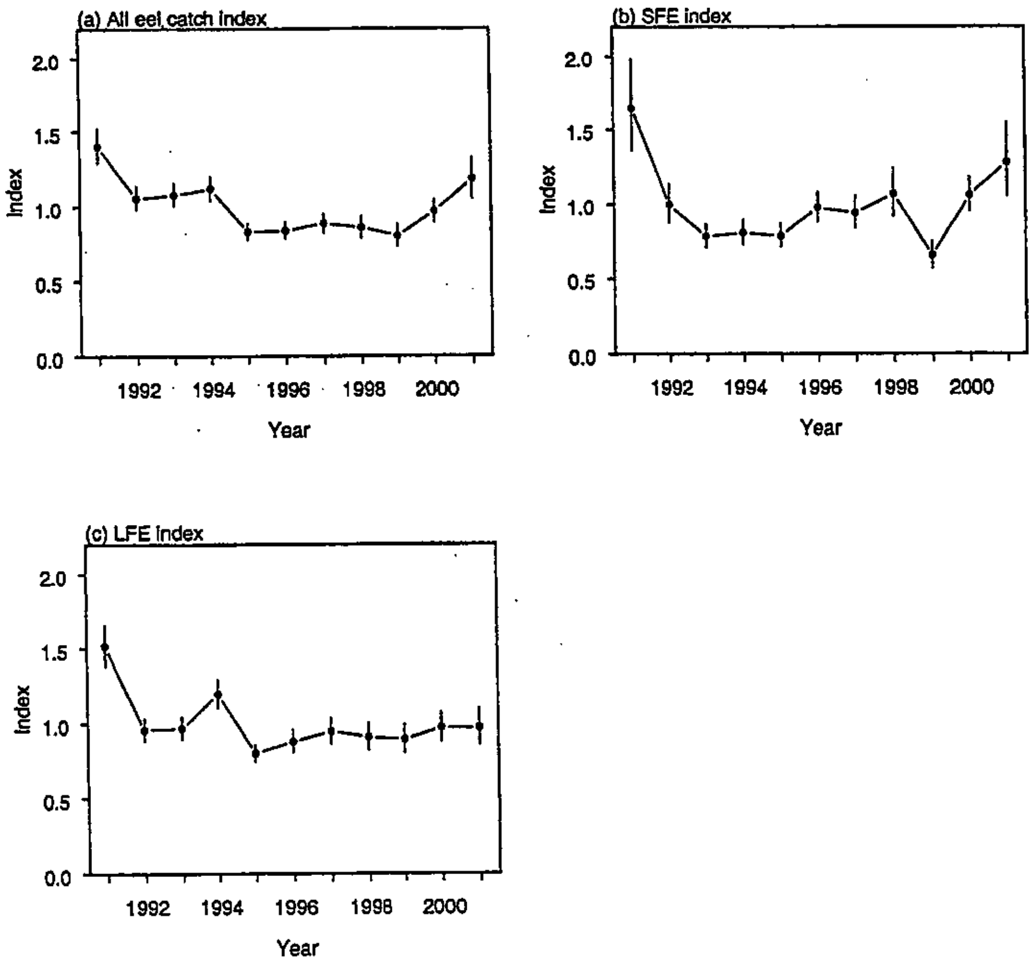

Figure 19: Standardised catch rate (catch per day) CPUE indices for (a) all eel catch, (b) SFE, and (c) LFE in ESAs 17–19 for the years 1990–91 to 2001–02.

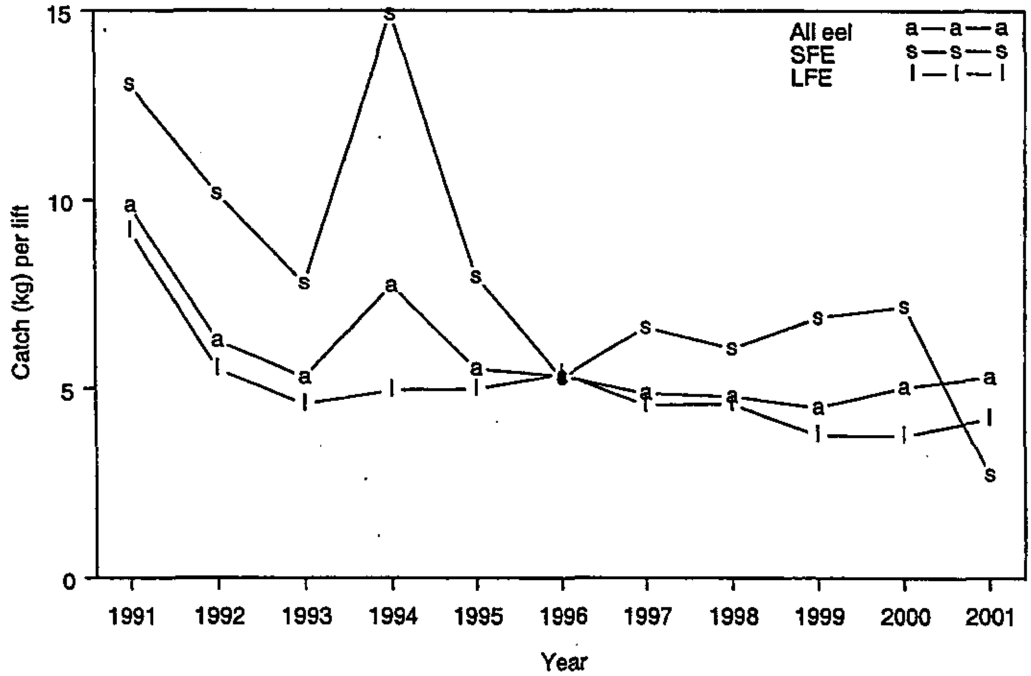

Figure 20: Unstandardised catch per lift (kg per lift) for SFE, LFE, and all eel catch in ESA 20 for the years 1990–91 to 2001–02.

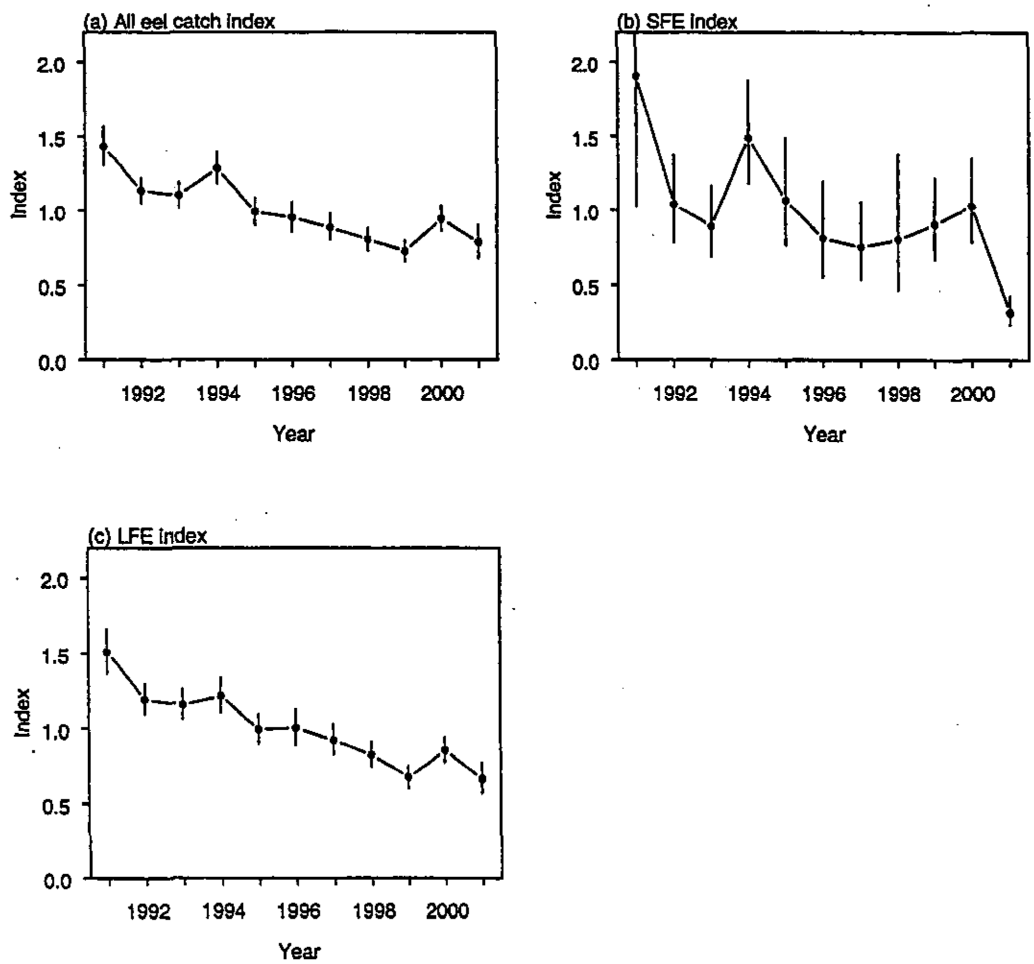

Figure 21: Standardised catch rate (catch per day) CPUE indices for (a) all eel catch, (b) SFE, and (c) LFE in ESA 20 for the years 1990–91 to 2001–02.

APPENDIX A: Additional data and data grooming

Table A1: Daily river flow data used in the standardised CPUE analyses.

ESA	River	Location	Source
2–3	Piako River	Site 9175, Kiwatahi	Environment Waikato
8–12	Wanganui River	Site 33301, Paetawa	NIWA
	Wairarapa River	Site 29202 Ruamahanga at Waihenga	Wellington Regional Council
17–19	Waitaki River	Site 71104, Kurow	Canterbury Regional Council
	Clutha River	Site 75207, Balclutha	NIWA
20	Mataura River	Site 77505, Parawa	Environment Southland

Table A2: Corrections (C) and deletions (D) to commercial eel fishery raw catch effort data for the fishing years 1990–91 to 1998–99 for all ESAs (1–21), and for 1999–2000 to 2000–01 for ESAs 2, 3, 8, 10, 11, 12, 17, 18, and 20.

	1990–91		1992–93		1993–94		1994–95	
Original cases		9 947		10 313		9 866		1 1170
	C	D	C	D	C	D	C	D
Net lifts	150	786	301	353	412	312.0	371	356
Catch weights	65	50	81	77	136	128.0	99	65
Area		110	0	176	0	240.0	0	457
Remaining cases		9 001		9 707		9 186		10 292
% corrections	2.2		3.7		5.6		4.2	
% deletions		9.5		5.9		6.9		7.9
% original cases		90.5		94.1		93.1		92.1

	1995–96		1996–97		1997–98		1998–99	
Original cases		1 1139		10 336		9 310		9 693
	C	D	C	D	C	D	C	D
Net lifts	348	466	388	462	377	535	309	521
Catch weights	318	100	331	376	527	198	353	271
Area	0	245	0	213	0	284	0	339
Remaining cases		10 328		9 285		8 293		8 562
% corrections	6		7		9.7		6.8	
% deletions		7.3		10.2		10.9		11.7
% original cases		92.7		89.8		89.1		88.3

	1999–2000		2000–01	
Original cases		3 673		3 008
	C	D	C	D
Net lifts	136	160	26	40
Catch weights	290	139	220	12
Area	0	1	0	10
Remaining cases		3 374		2 956
% corrections	11.6		8.2	
% deletions		8.2		2.1
% original cases		91.9		98.3

Table A3: Summary of catch and effort data for eel return areas. See Figure 1 for locations of ESAs. ESA, eel return area; EEU, eels unidentified; SFE, shortfinned eel; LFE, longfinned eel; CPUE, catch per unit effort; s.e., standard error. CPUE (kg/lift) is the mean daily value.

ESA 2 and 3

	No. fishing	Total estimated		% records target			Unstandardised	
Fishing year	days	catch (kg)	No. of lifts	EEU	LFE	SFE	CPUE (kg/lift)	s.e.
1990–91	1 004	113 840	25 104	71.2	6.7	22.1	4.75	0.13
1991–92	949	097 947	21 958	53.8	6.6	39.5	4.86	0.13
1992–93	895	104 280	22 999	46.3	9.4	44.4	4.36	0.09
1993–94	482	048 179	11 300	37.1	8.3	54.6	4.44	0.13
1994–95	995	130 365	26 672	43.8	7.0	49.1	4.68	0.09
1995–96	845	123 646	23 313	36.6	6.7	56.7	5.26	0.12
1996–97	1 054	119 995	27 626	26.2	16.6	57.2	4.66	0.10
1997–98	831	111 148	21 902	34.8	21.8	43.4	5.06	0.12
1998–99	890	126 683	23 261	31.6	13.8	54.6	4.89	0.11
1999–2000	1 140	134 629	30 401	12.3	19.8	67.9	4.43	0.08
2000–01	898	103 027	24 515	0.0	20.6	79.4	4.39	0.09
Total	9 983	1 213 739	259 051	35.6	12.7	51.7		

ESA 8–12

	No. fishing	Total estimated		% records target			Unstandardised	
Fishing year	days	catch (kg)	No. of lifts	EEU	LFE	SFE	CPUE (kg/lift)	s.e.
1990–91	449	89 180	13 648	61.0	16.5	22.5	6.69	0.25
1991–92	354	108 321	10 175	53.4	25.7	20.9	12.04	0.50
1992–93	494	116 355	13 208	88.7	9.1	2.2	10.11	0.40
1993–94	630	129 056	15 685	67.6	19.4	13.0	8.39	0.27
1994–95	742	153 624	18 878	83.0	6.9	10.1	8.59	0.25
1995–96	596	108 318	17 288	70.8	18.8	10.4	6.65	0.24
1996–97	683	101 958	18 648	65.9	16.7	17.4	5.78	0.19
1997–98	628	111 286	19 441	62.1	18.5	19.4	5.69	0.18
1998–99	747	114 646	19 144	67.5	22.6	9.9	6.26	0.15
1999–2000	904	136 437	27 557	38.1	26.4	35.5	5.45	0.15
2000–01	1 001	149 754	28 079	0.0	39.0	61.0	5.22	0.11
Total	7 228	1 318 935	201 751	56.1	21.1	22.9		

ESA 17–19

	No. fishing	Total estimated		% records target			Unstandardised	
Fishing year	days	catch (kg)	No. of lifts	EEU	LFE	SFE	CPUE (kg/lift)	s.e.
1990–91	695	94 368	15 456	0.0	77.3	22.7	6.80	0.18
1991–92	880	114 634	23 280	1.3	64.1	34.7	5.42	0.16
1992–93	967	116 581	26 057	2.0	60.6	37.4	5.02	0.12
1993–94	876	113 818	26 149	6.8	65.9	27.3	4.81	0.13
1994–95	1 109	116 875	33 267	1.3	68.4	30.3	3.84	0.09
1995–96	1 085	105 570	26 746	19.9	52.6	27.5	4.29	0.13
1996–97	826	68 315	18 816	16.0	54.0	30.0	4.30	0.15
1997–98	645	56 490	16 011	6.2	69.3	24.5	4.60	0.23
1998–99	583	59 320	15 053	6.3	62.1	31.6	3.87	0.11
1999–2000	665	72 806	16 536	1.4	58.8	39.8	4.95	0.16
2000–01	562	51 902	13 795	0.0	71.9	28.1	4.43	0.14
Total	8 893	970 679	231 166	6.0	63.5	30.5		

Table A3 – ***continued***

ESA 20

Fishing year	No. fishing days	Total estimated catch (kg)	No. of lifts	% records target EEU	LFE	SFE	Unstandardised CPUE (kg/lift)	s.e.
1990–91	510	93 735	14 196	0.0	95.5	4.5	9.67	0.51
1991–92	789	118 779	24 128	0.0	83.7	16.3	6.34	0.21
1992–93	756	105 463	24 376	0.1	83.2	16.7	5.24	0.15
1993–94	615	103 226	20 335	0.2	82.4	17.4	7.39	0.41
1994–95	500	72 898	16 527	0.0	85.6	14.4	5.43	0.23
1995–96	371	56 893	11 526	3.2	82.5	14.3	5.33	0.18
1996–97	426	61 507	13 178	0.2	86.2	13.6	4.88	0.14
1997–98	445	57 052	12 840	0.4	87.6	11.9	4.80	0.18
1998–99	482	53 252	13 474	1.0	78.8	20.1	4.56	0.16
1999–2000	581	73 324	18 086	3.4	77.5	19.1	5.03	0.21
2000–01	310	51 748	10 124	0.0	71.3	28.7	5.30	0.20
Total	5 785	847 877	178 790	0.7	83.4	15.9		

APPENDIX B: CPUE indices and model diagnostics

Table B1: ESA 2–3 CPUE indices for (a) total catch, (b) SFE, and (c) LFE.

ESA 2–3 (Total catch)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	0.98	0.91	1.05	0.04	0.04
1992	1.06	0.99	1.14	0.04	0.04
1993	1.00	0.94	1.07	0.03	0.03
1994	0.99	0.91	1.09	0.05	0.05
1995	1.02	0.95	1.08	0.03	0.03
1996	1.07	1.00	1.15	0.04	0.04
1997	0.91	0.85	0.97	0.03	0.03
1998	1.04	0.97	1.12	0.04	0.04
1999	1.04	0.97	1.11	0.04	0.04
2000	0.97	0.91	1.03	0.03	0.03
2001	0.94	0.88	1.01	0.04	0.04

ESA 2–3 (SFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.05	0.92	1.21	0.07	0.07
1992	1.00	0.90	1.10	0.05	0.05
1993	1.00	0.91	1.10	0.05	0.05
1994	1.04	0.93	1.16	0.06	0.06
1995	1.12	1.03	1.21	0.04	0.04
1996	1.18	1.08	1.29	0.05	0.05
1997	0.85	0.78	0.92	0.04	0.04
1998	1.03	0.94	1.13	0.05	0.05
1999	1.06	0.97	1.15	0.04	0.04
2000	0.90	0.84	0.97	0.04	0.04
2001	0.84	0.77	0.91	0.04	0.04

ESA 2–3 (LFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.64	1.36	1.97	0.09	0.09
1992	1.73	1.47	2.03	0.08	0.08
1993	1.50	1.30	1.72	0.07	0.07
1994	0.92	0.78	1.08	0.08	0.08
1995	1.10	0.97	1.25	0.06	0.06
1996	0.85	0.71	1.01	0.09	0.09
1997	0.79	0.69	0.90	0.07	0.07
1998	0.87	0.76	0.98	0.06	0.06
1999	0.76	0.66	0.89	0.08	0.08
2000	0.76	0.68	0.85	0.06	0.06
2001	0.70	0.62	0.78	0.06	0.06

Table B2: ESA 8–12 CPUE indices for (a) total catch, (b) SFE, and (c) LFE.

ESA 8–12 (Total catch)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.38	1.25	1.53	0.05	0.05
1992	1.71	1.53	1.91	0.06	0.06
1993	1.40	1.28	1.53	0.05	0.05
1994	1.10	1.01	1.19	0.04	0.04
1995	1.07	0.99	1.16	0.04	0.04
1996	0.97	0.89	1.05	0.04	0.04
1997	0.83	0.76	0.90	0.04	0.04
1998	0.81	0.75	0.88	0.04	0.04
1999	0.77	0.71	0.83	0.04	0.04
2000	0.76	0.70	0.81	0.04	0.04
2001	0.68	0.64	0.73	0.03	0.03

ESA 8–12 (SFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	2.92	2.38	3.59	0.10	0.10
1992	4.90	3.87	6.22	0.12	0.12
1993	1.04	0.87	1.25	0.09	0.09
1994	0.77	0.67	0.89	0.07	0.07
1995	0.70	0.62	0.80	0.07	0.07
1996	0.74	0.64	0.85	0.07	0.07
1997	0.49	0.42	0.57	0.08	0.08
1998	0.75	0.65	0.86	0.07	0.07
1999	0.85	0.73	0.98	0.08	0.08
2000	0.77	0.70	0.85	0.05	0.05
2001	0.70	0.63	0.76	0.05	0.05

ESA 8–12 (LFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.39	1.19	1.63	0.08	0.08
1992	1.63	1.33	1.99	0.10	0.10
1993	1.31	1.13	1.50	0.07	0.07
1994	1.11	0.97	1.26	0.06	0.06
1995	0.99	0.88	1.12	0.06	0.06
1996	1.02	0.90	1.15	0.06	0.06
1997	1.03	0.90	1.17	0.07	0.07
1998	0.74	0.64	0.84	0.07	0.07
1999	0.81	0.72	0.92	0.06	0.06
2000	0.73	0.65	0.80	0.05	0.05
2001	0.68	0.62	0.75	0.05	0.05

Table B3: ESA 17–19 CPUE indices for (a) total catch, (b) SFE, and (c) LFE.

ESA 17–19 (Total catch)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.42	1.31	1.54	0.04	0.04
1992	1.07	1.00	1.15	0.04	0.04
1993	1.09	1.02	1.17	0.03	0.03
1994	1.14	1.06	1.22	0.03	0.03
1995	0.84	0.79	0.89	0.03	0.03
1996	0.85	0.80	0.90	0.03	0.03
1997	0.90	0.83	0.96	0.04	0.04
1998	0.87	0.80	0.95	0.04	0.04
1999	0.81	0.74	0.89	0.05	0.05
2000	0.98	0.91	1.06	0.04	0.04
2001	1.20	1.07	1.34	0.06	0.06

ESA 17–19 (SFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.70	1.41	2.05	0.09	0.09
1992	1.03	0.91	1.17	0.06	0.06
1993	0.81	0.73	0.89	0.05	0.05
1994	0.83	0.75	0.92	0.05	0.05
1995	0.81	0.73	0.90	0.05	0.05
1996	1.01	0.91	1.11	0.05	0.05
1997	0.97	0.87	1.09	0.06	0.06
1998	1.10	0.95	1.28	0.08	0.08
1999	0.68	0.59	0.77	0.07	0.07
2000	1.10	0.98	1.22	0.05	0.05
2001	1.32	1.09	1.60	0.10	0.10

ESA 17–19 (LFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.54	1.40	1.68	0.05	0.05
1992	0.97	0.90	1.05	0.04	0.04
1993	0.98	0.91	1.06	0.04	0.04
1994	1.21	1.12	1.31	0.04	0.04
1995	0.81	0.76	0.87	0.04	0.04
1996	0.89	0.82	0.97	0.04	0.04
1997	0.96	0.88	1.05	0.04	0.04
1998	0.92	0.84	1.02	0.05	0.05
1999	0.91	0.82	1.01	0.05	0.05
2000	0.99	0.90	1.09	0.05	0.05
2001	0.99	0.87	1.11	0.06	0.06

Table B4: ESA 20 CPUE indices for (a) total catch, (b) SFE, and (c) LFE.

ESA 20 (Total catch)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.46	1.33	1.60	0.05	0.05
1992	1.15	1.07	1.24	0.04	0.04
1993	1.12	1.04	1.21	0.04	0.04
1994	1.31	1.20	1.42	0.04	0.04
1995	1.01	0.92	1.10	0.04	0.04
1996	0.97	0.87	1.07	0.05	0.05
1997	0.90	0.82	0.99	0.05	0.05
1998	0.82	0.74	0.90	0.05	0.05
1999	0.74	0.67	0.81	0.05	0.05
2000	0.96	0.88	1.05	0.04	0.04
2001	0.80	0.69	0.92	0.07	0.07

ESA 20 (SFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	2.07	1.12	3.84	0.31	0.32
1992	1.13	0.85	1.49	0.14	0.14
1993	0.97	0.75	1.26	0.13	0.13
1994	1.62	1.28	2.04	0.12	0.12
1995	1.16	0.83	1.62	0.17	0.17
1996	0.88	0.60	1.30	0.20	0.20
1997	0.82	0.58	1.15	0.17	0.17
1998	0.87	0.51	1.50	0.27	0.28
1999	0.98	0.73	1.33	0.15	0.15
2000	1.12	0.85	1.47	0.14	0.14
2001	0.34	0.25	0.46	0.15	0.15

ESA 20 (LFE)

Year	Index	Lower C.I.	Upper C.I.	s.e.	c.v.
1991	1.55	1.41	1.70	0.05	0.05
1992	1.23	1.13	1.33	0.04	0.04
1993	1.19	1.10	1.30	0.04	0.04
1994	1.25	1.14	1.38	0.05	0.05
1995	1.02	0.93	1.13	0.05	0.05
1996	1.03	0.92	1.16	0.06	0.06
1997	0.95	0.85	1.06	0.05	0.05
1998	0.85	0.77	0.94	0.05	0.05
1999	0.69	0.62	0.77	0.05	0.05
2000	0.88	0.80	0.97	0.05	0.05
2001	0.68	0.59	0.79	0.08	0.08

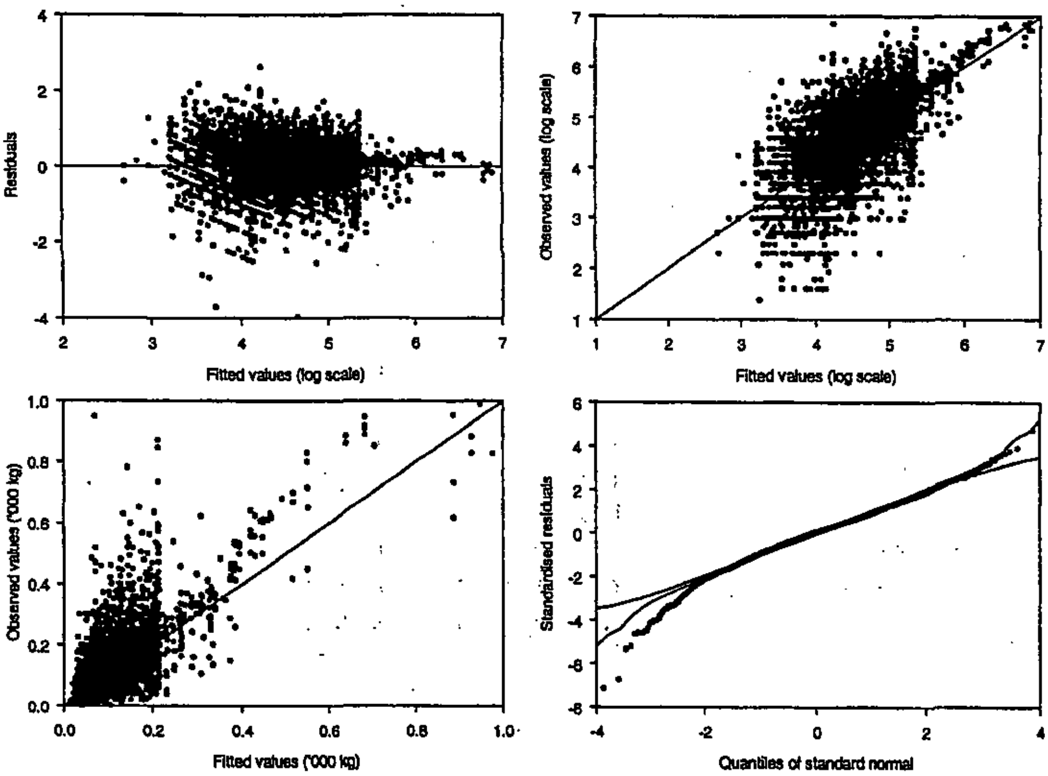

Figure B1: Residual diagnostic plots for the all eel CPUE model in ESAs 2–3 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

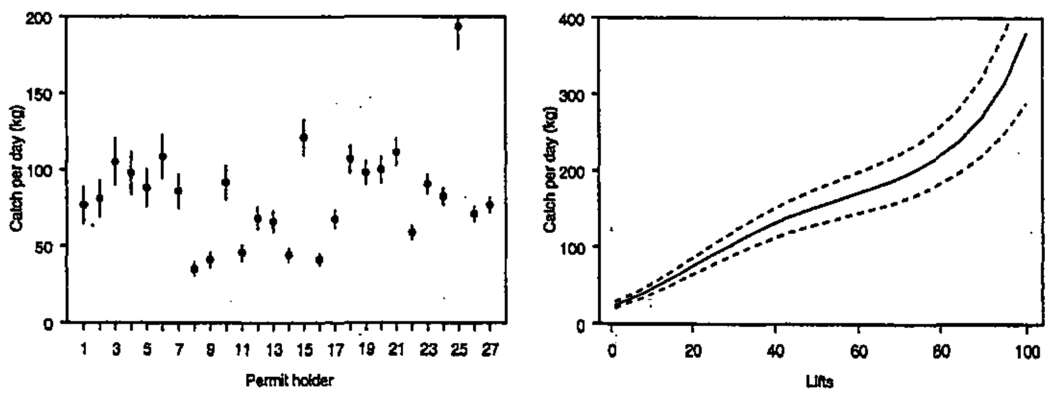

Figure B2: Expected catch rates (catch per day) for the all eel CPUE model in ESAs 2–3 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

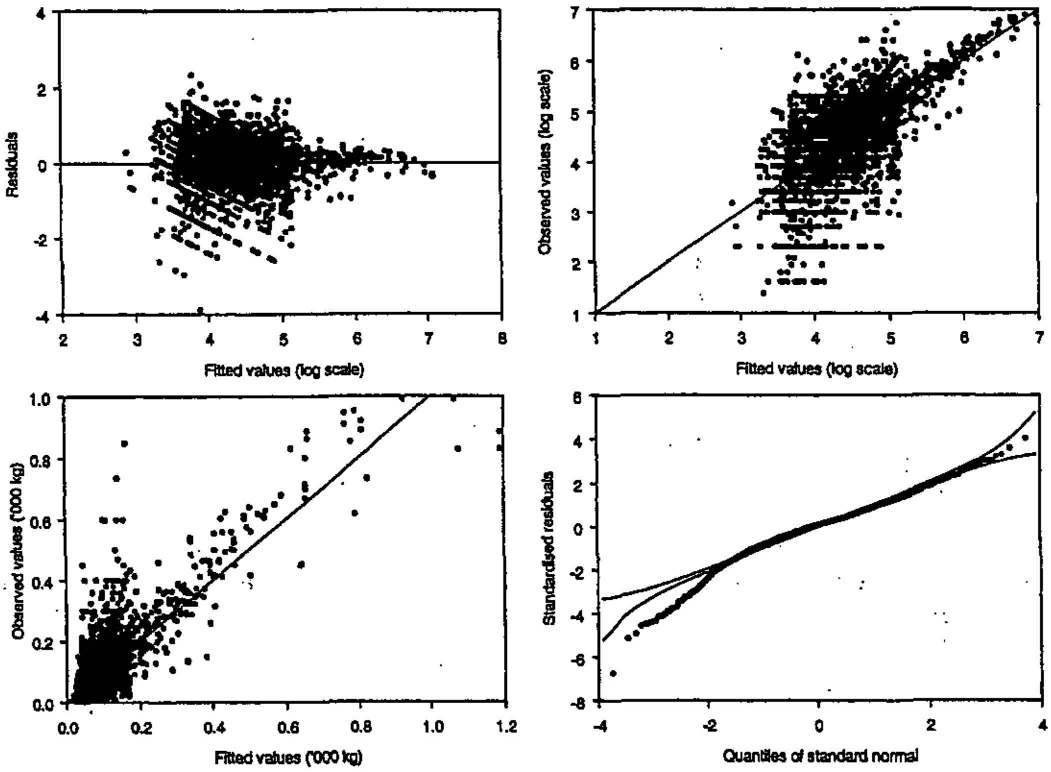

Figure B3: Residual diagnostic plots for the SFE CPUE model in ESAs 2–3 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

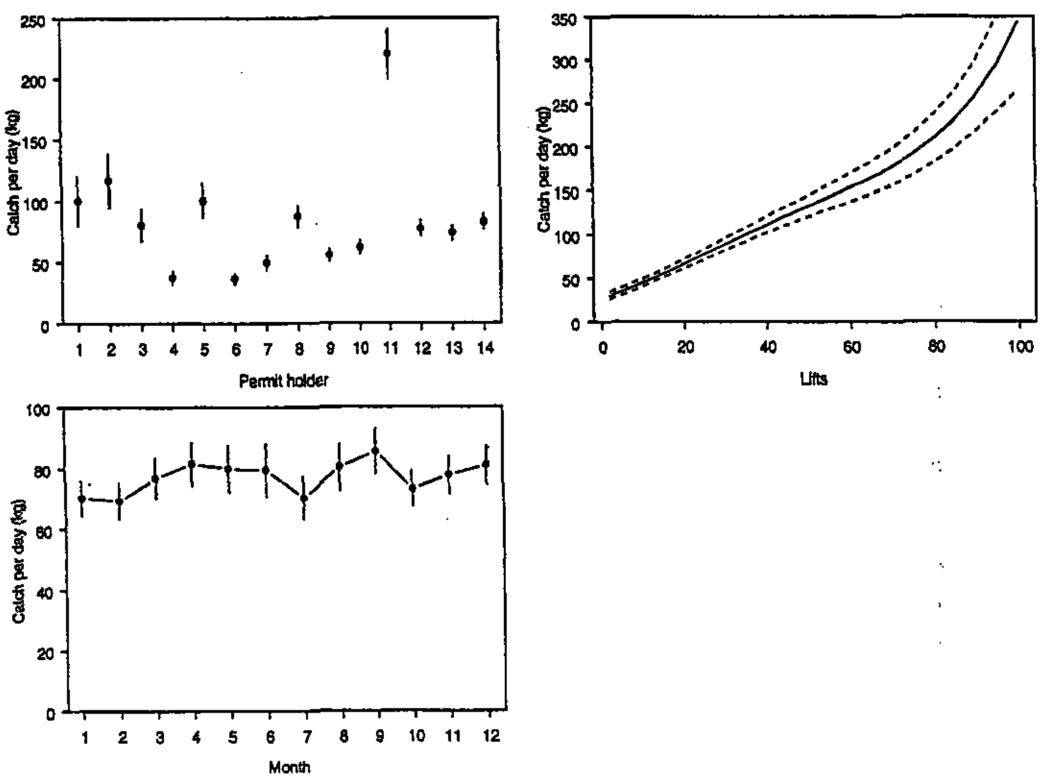

Figure B4: Expected catch rates (catch per day) for the SFE CPUE model in ESAs 2–3 for the years 1990–91 *to* 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

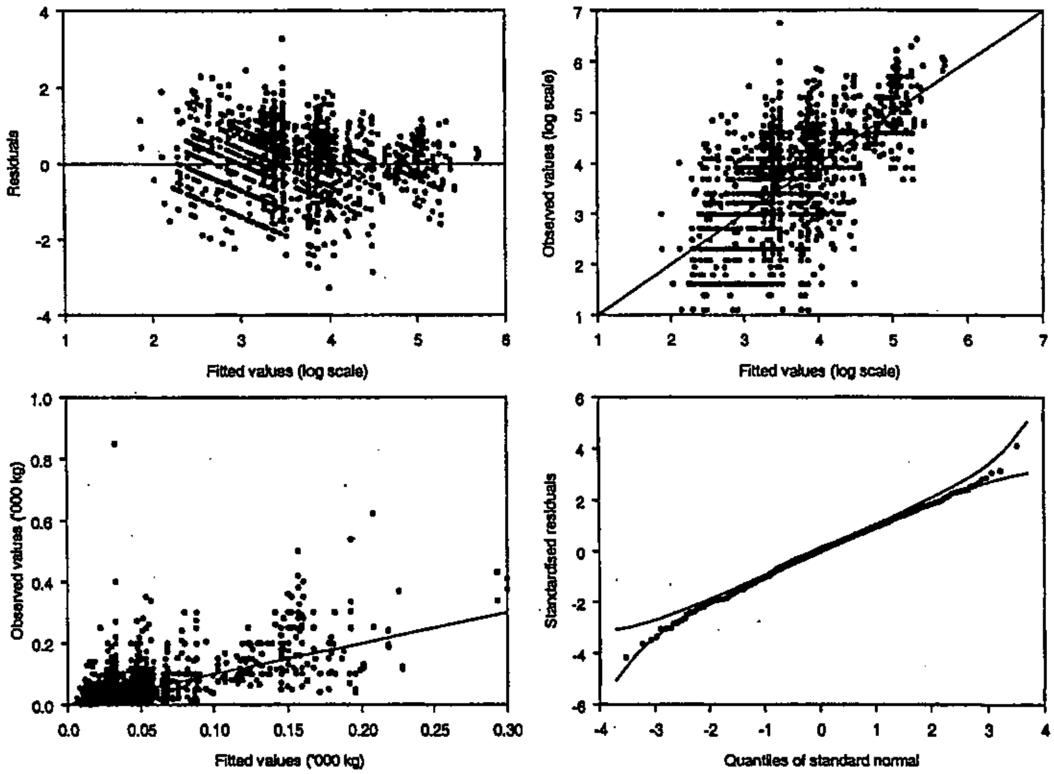

Figure B5: Residual diagnostic plots for the LFE CPUE model in ESAs 2–3 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

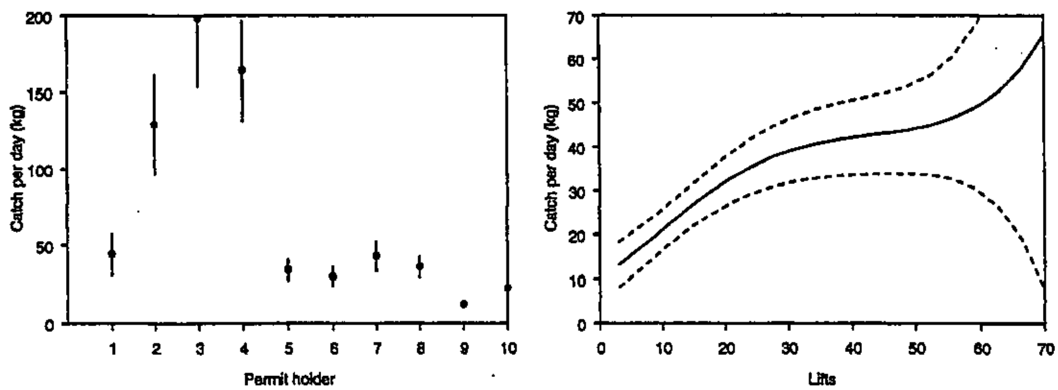

Figure B6: Expected catch rates (catch per day) for the LFE CPUE model in ESAs 2–3 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

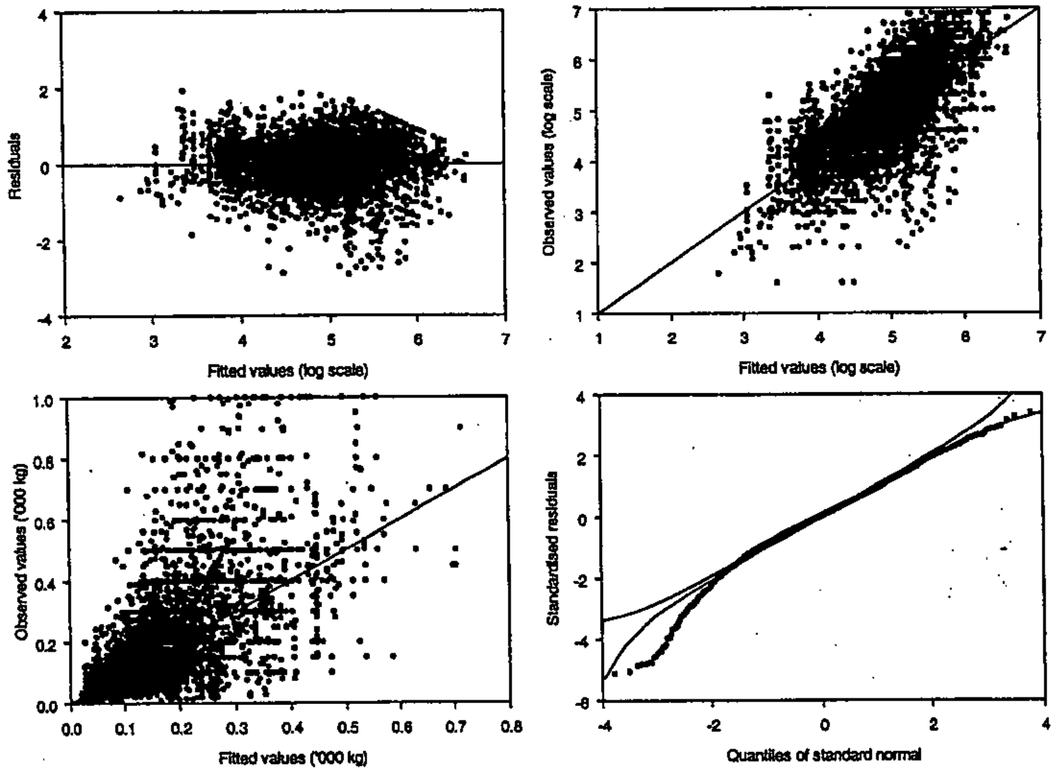

Figure B7: Residual diagnostic plots for the all eel CPUE model in ESAs 8–12 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

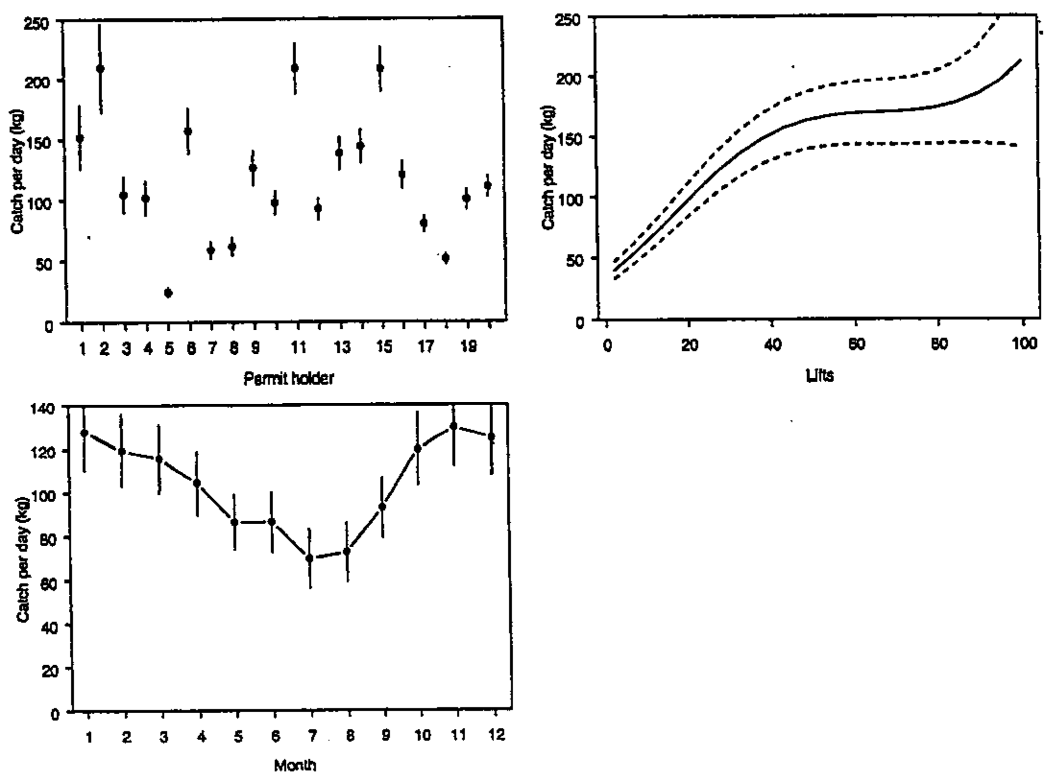

Figure B8: Expected catch rates (catch per day) for the all eel CPUE model in ESAs 8–12 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

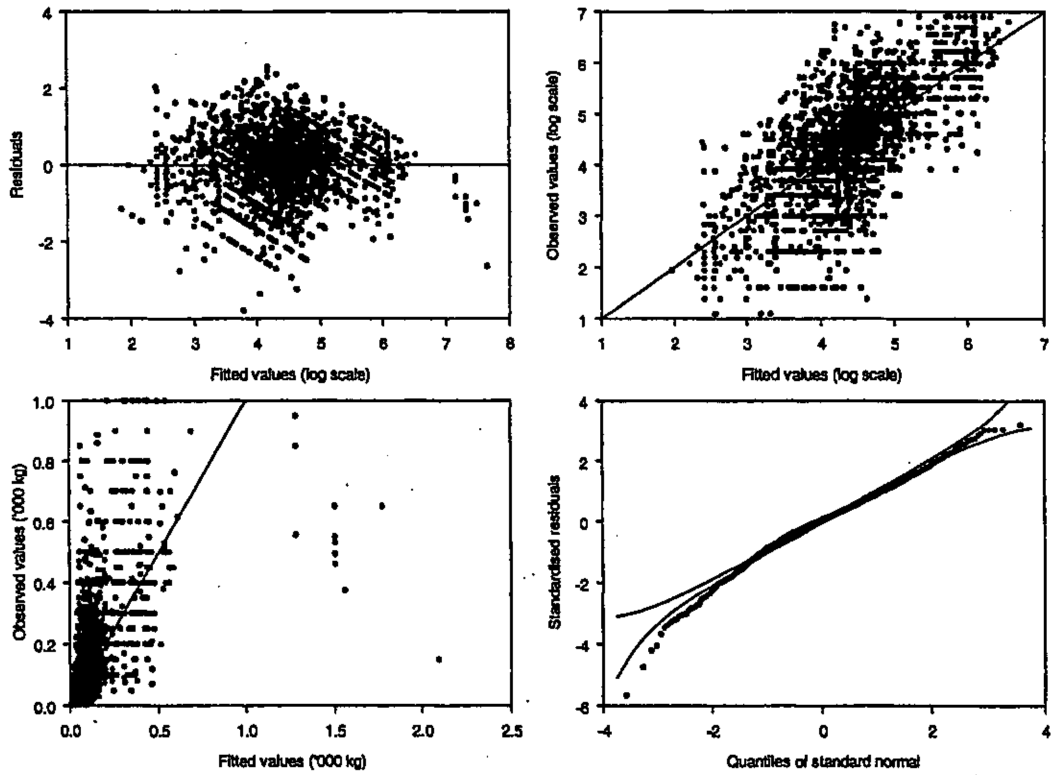

Figure B9: Residual diagnostic plots for the SFE CPUE model in ESAs 8–12 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

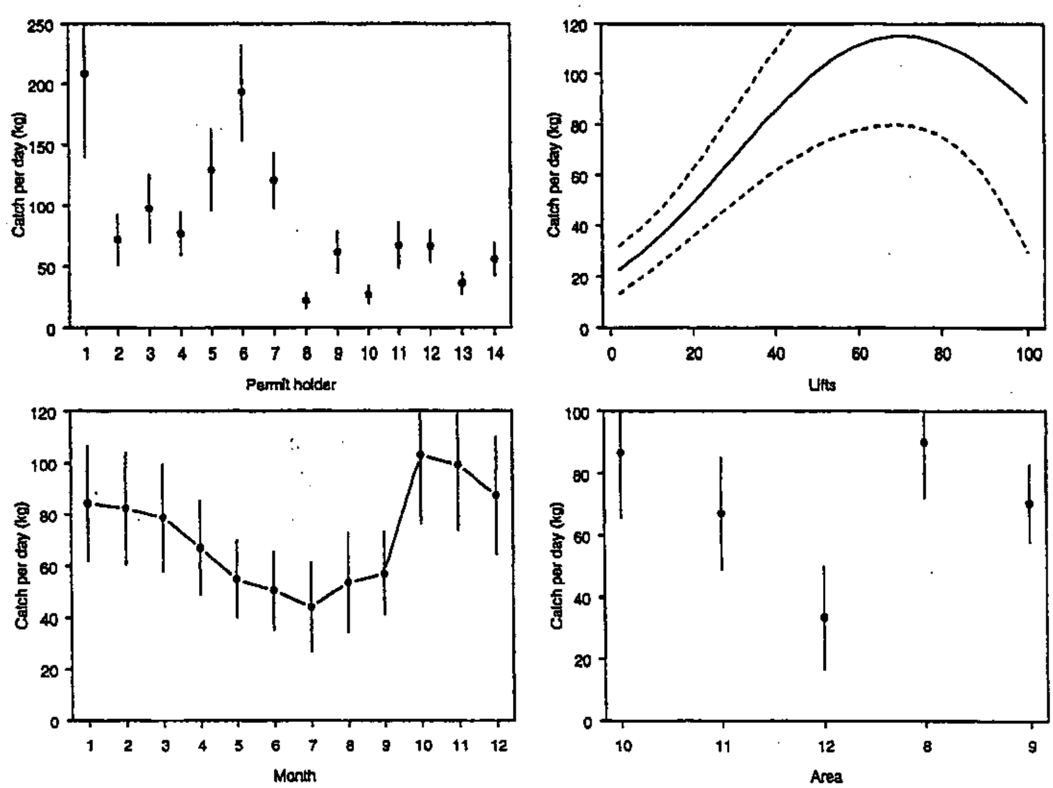

Figure B10: Expected catch rates (catch per day) for the SFE CPUE model in ESAs 8–12 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

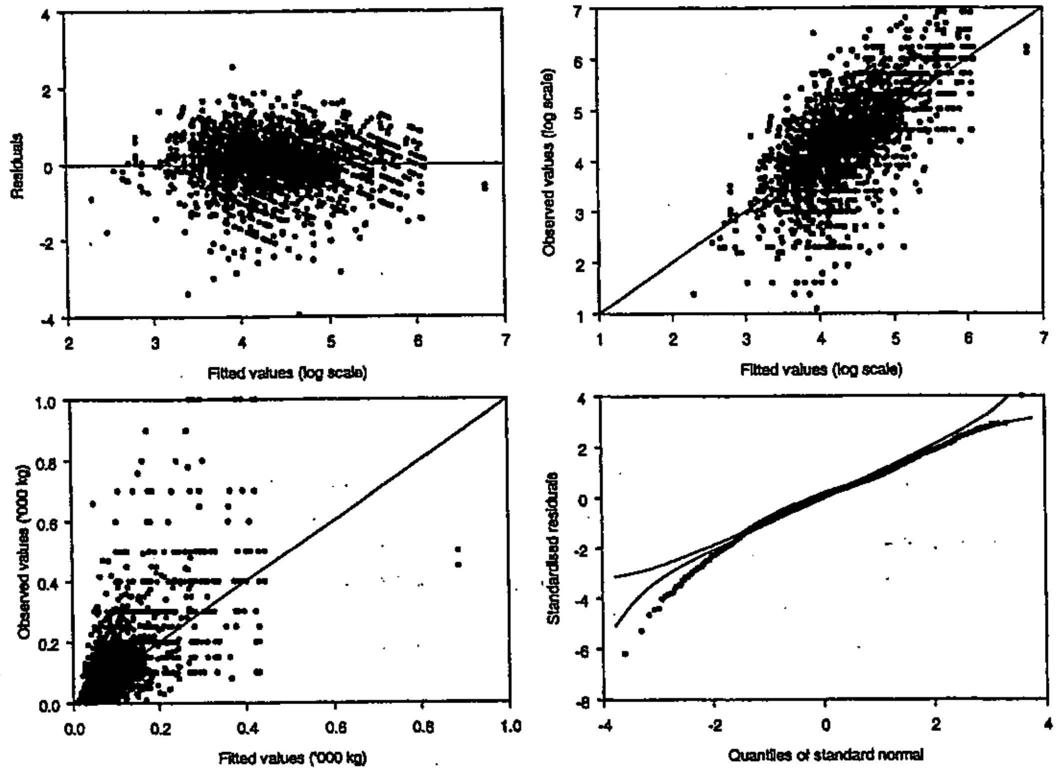

Figure B11: Residual diagnostic plots for the LFE CPUE model in ESAs 8–12 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

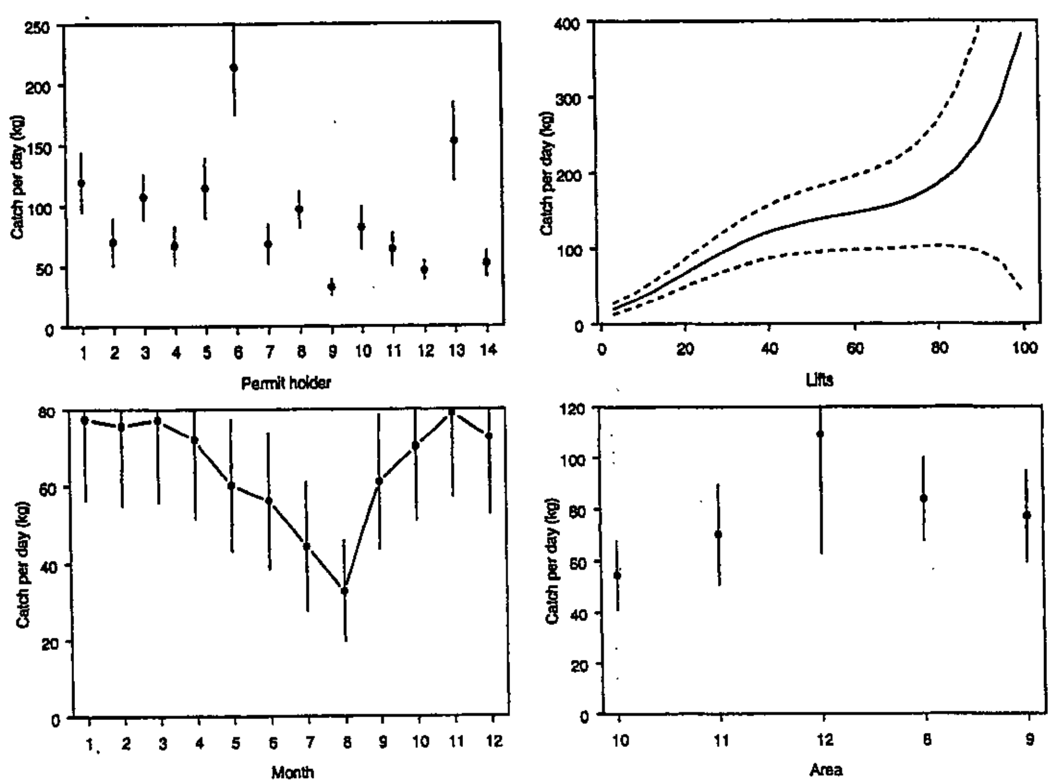

Figure B12: Expected catch rates (catch per day) for the LFE CPUE model in ESAs 8–12 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

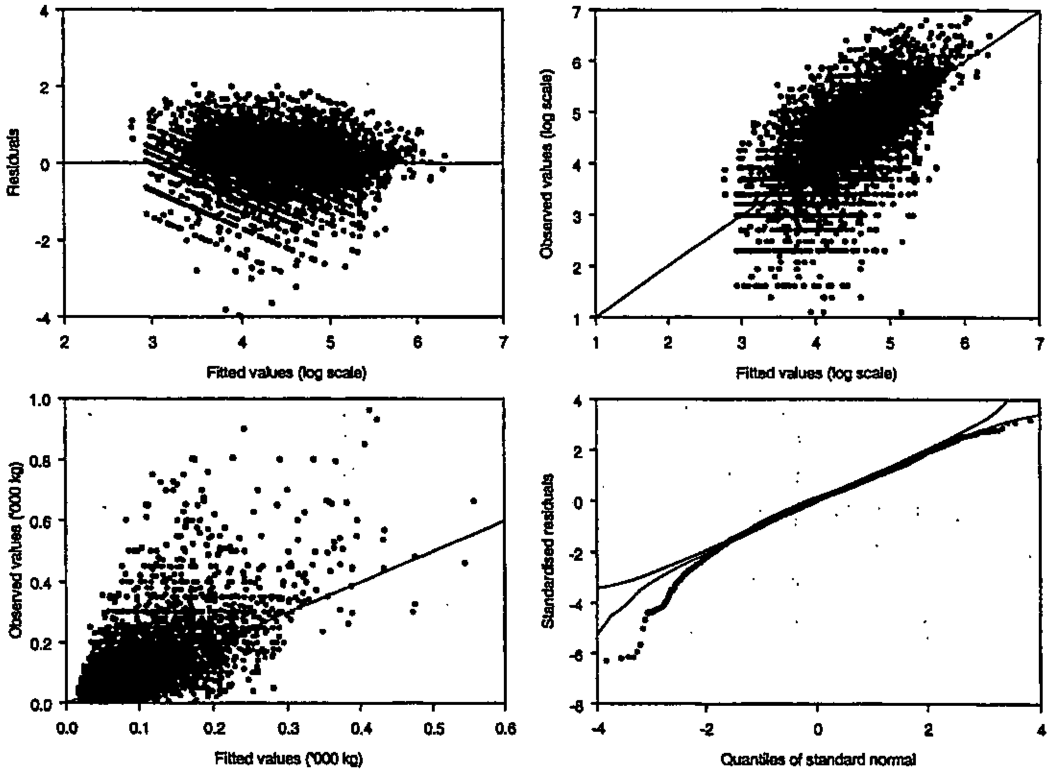

Figure B13: Residual diagnostic plots for the all eel CPUE model in ESAs 17–19 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

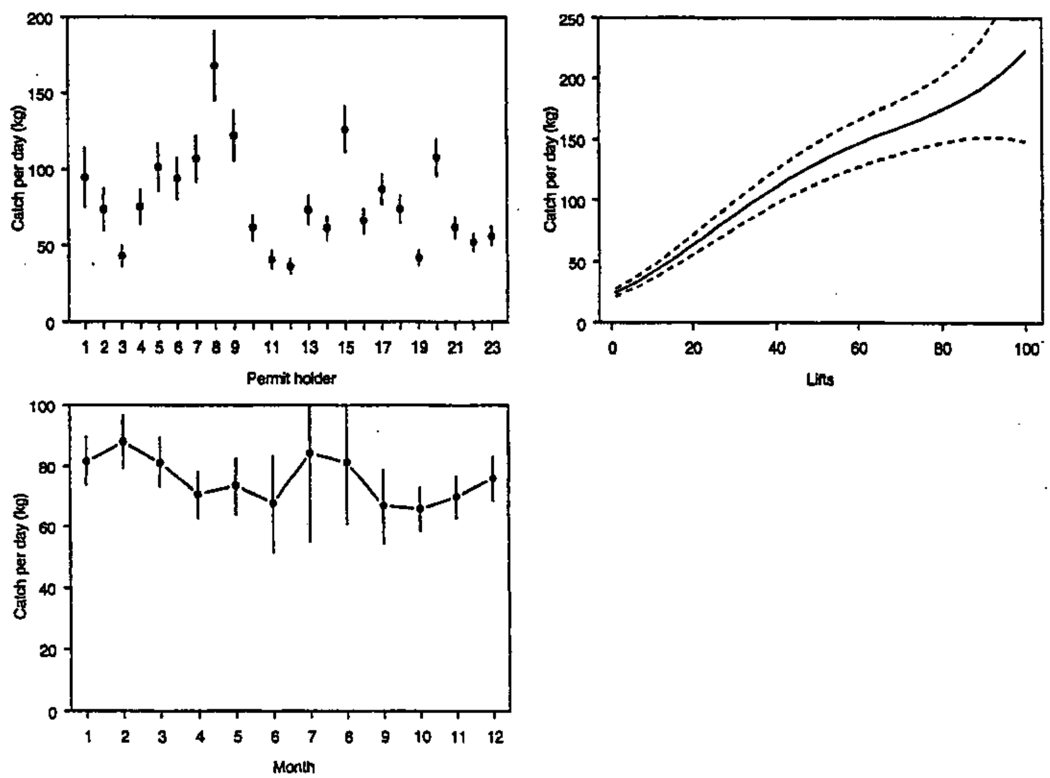

Figure B14: Expected catch rates (catch per day) for the all eel CPUE model in ESAs 17–19 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

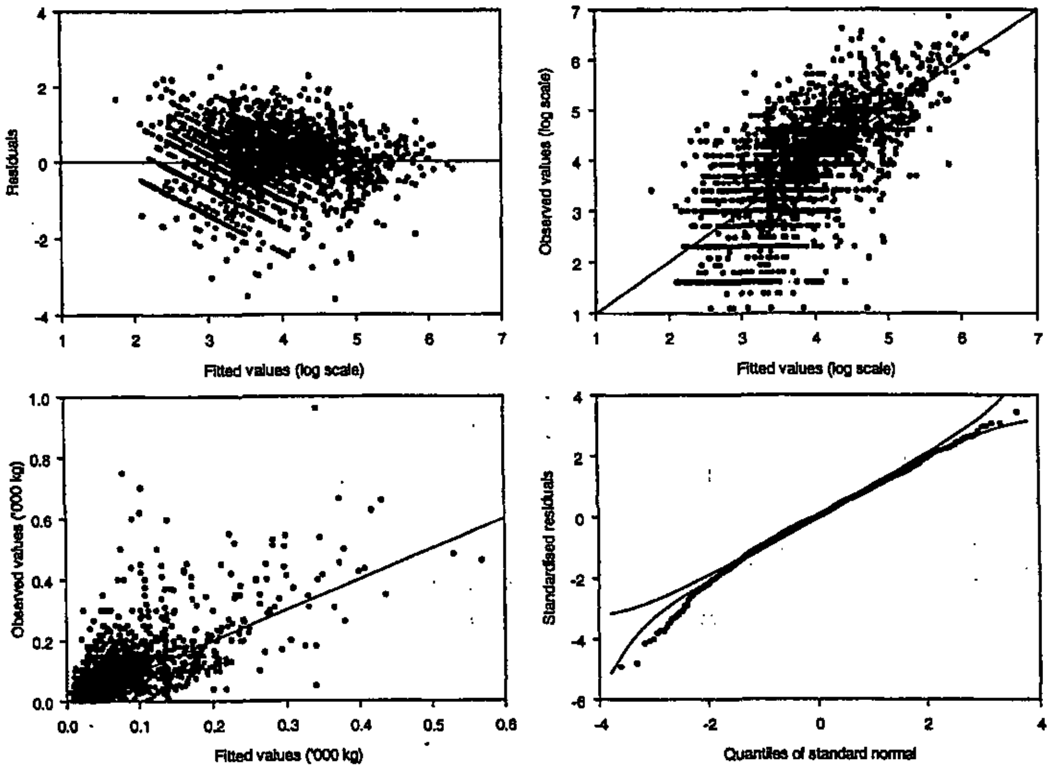

Figure B15: Residual diagnostic plots for the SFE CPUE model in ESAs 17–19 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

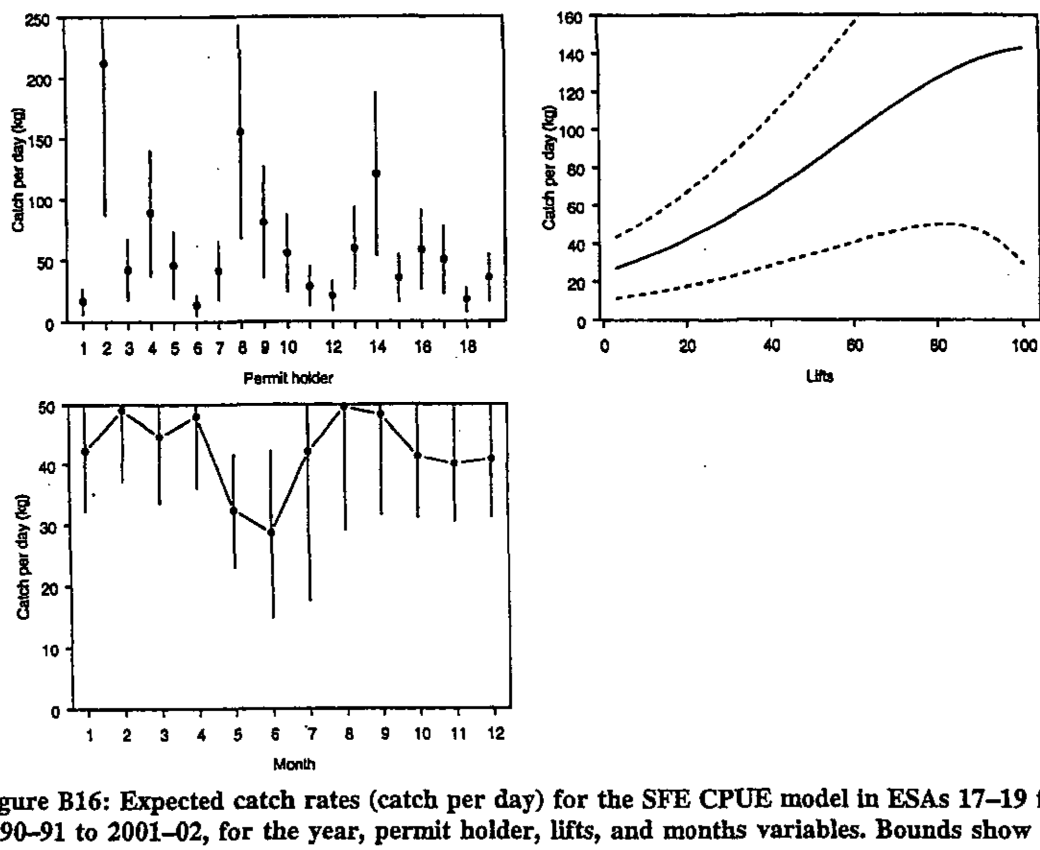

Figure B16: Expected catch rates (catch per day) for the SFE CPUE model in ESAs 17–19 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

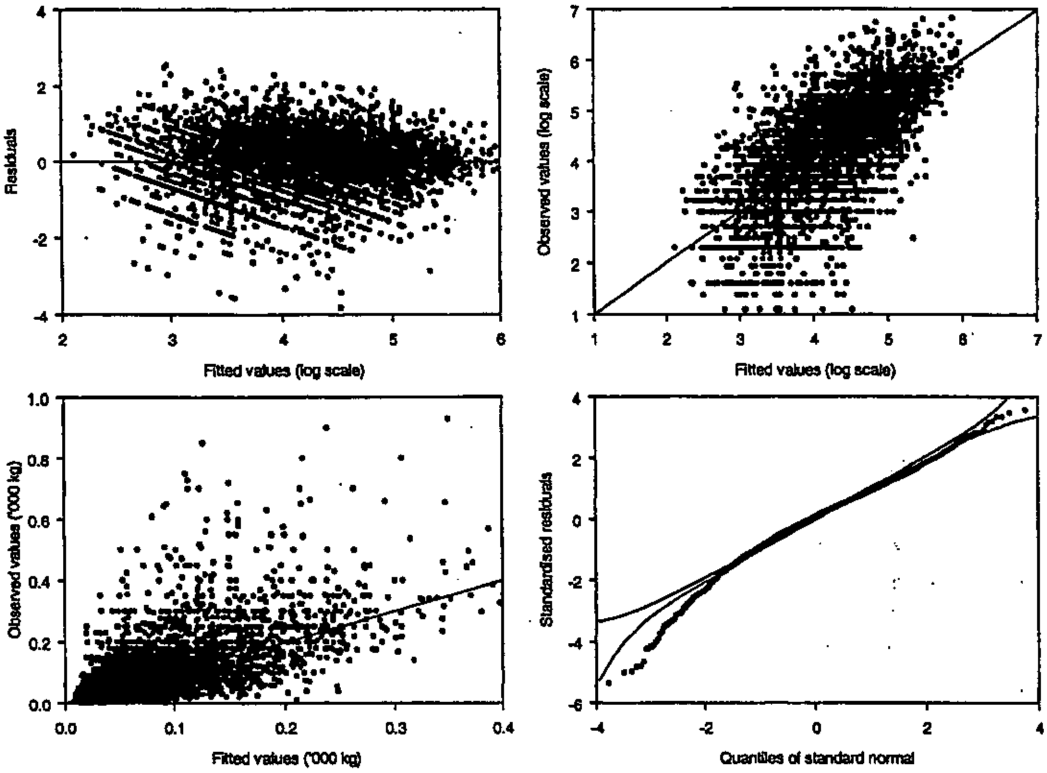

Figure B17: Residual diagnostic plots for the LFE CPUE model in ESAs 17–19 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

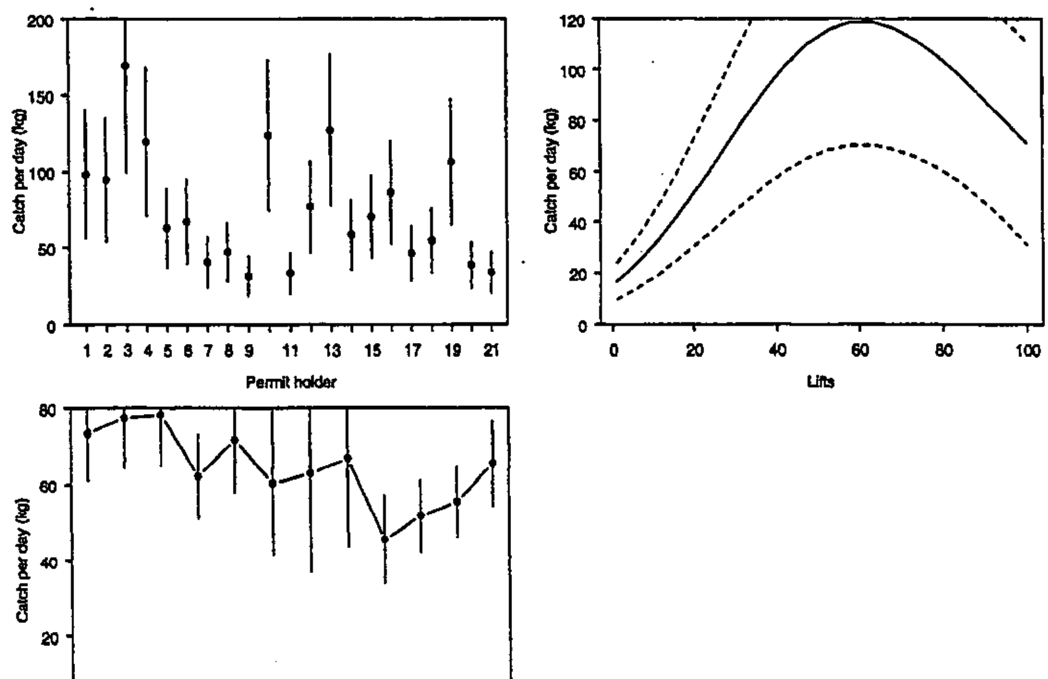

Figure B18: Expected catch rates (catch per day) for the LFE CPUE model in ESAs 17–19 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

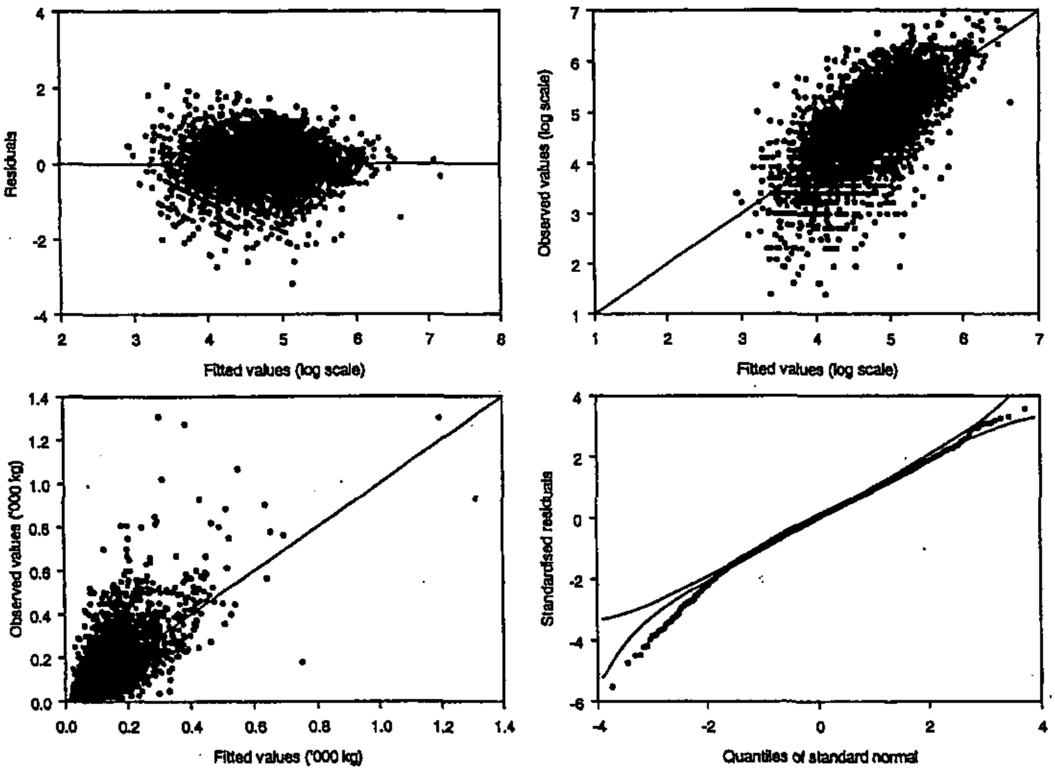

Figure B19: Residual diagnostic plots for the all eel CPUE model in ESA 20 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

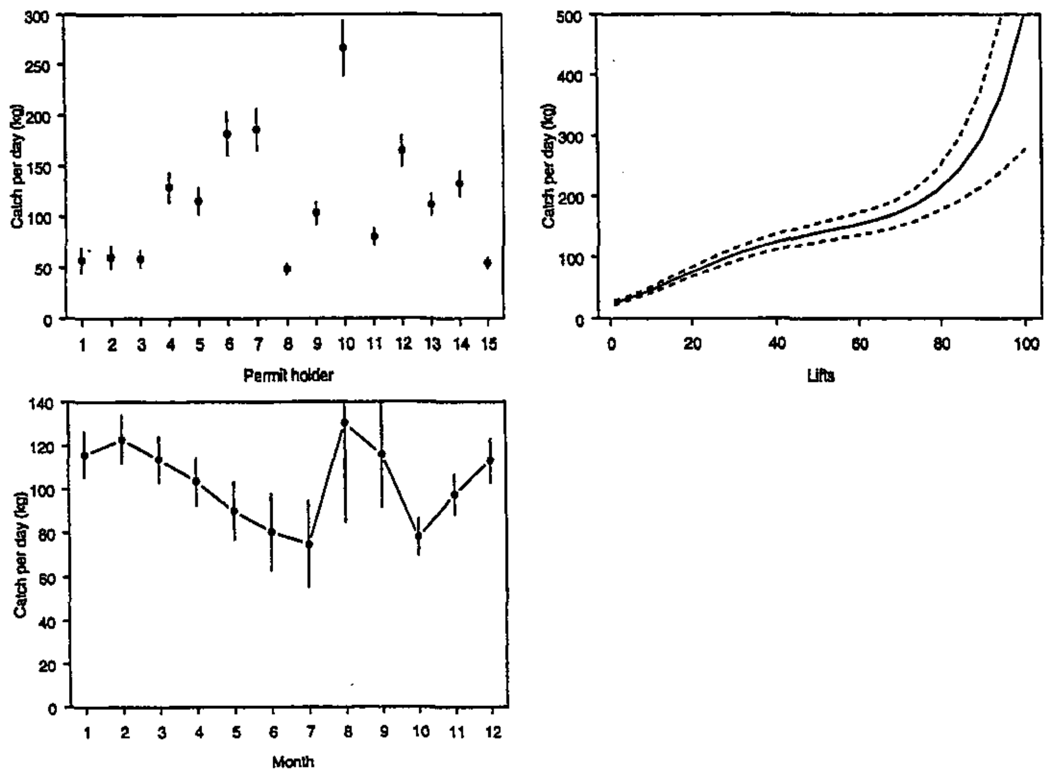

Figure B20: Expected catch rates (catch per day) for the all eel CPUE model in ESA 20 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

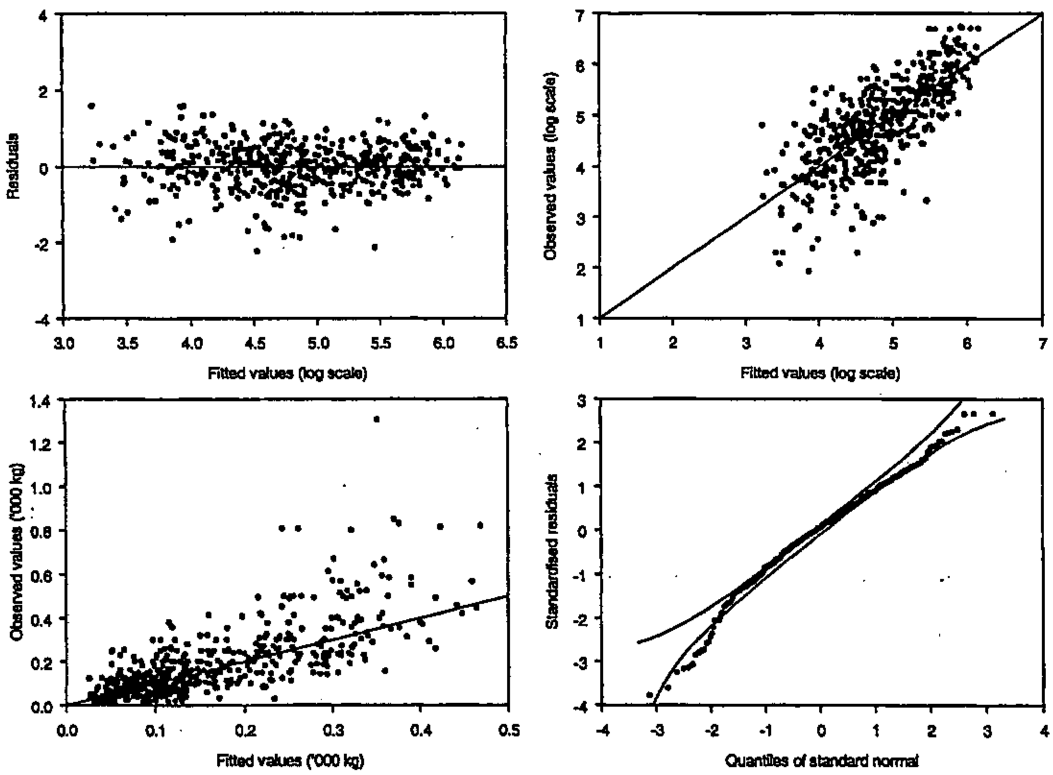

Figure B21: Residual diagnostic plots for the SFE CPUE model in ESA 20 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

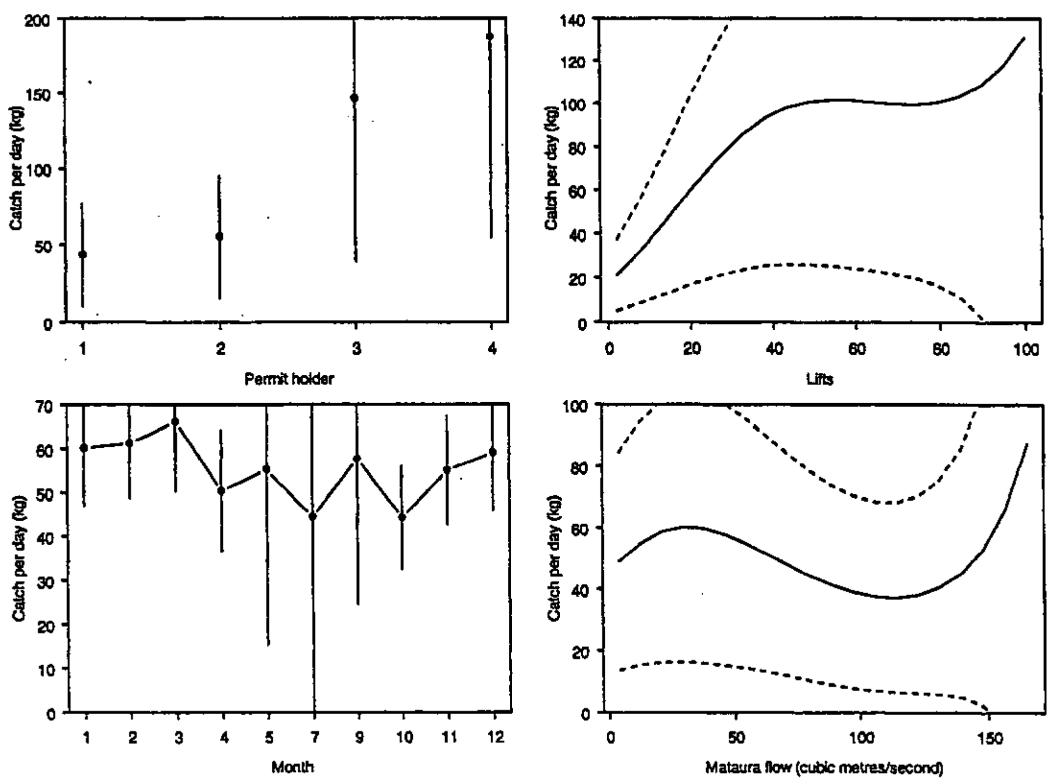

Figure B22: Expected catch rates (catch per day) for the SFE CPUE model in ESA 20 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.

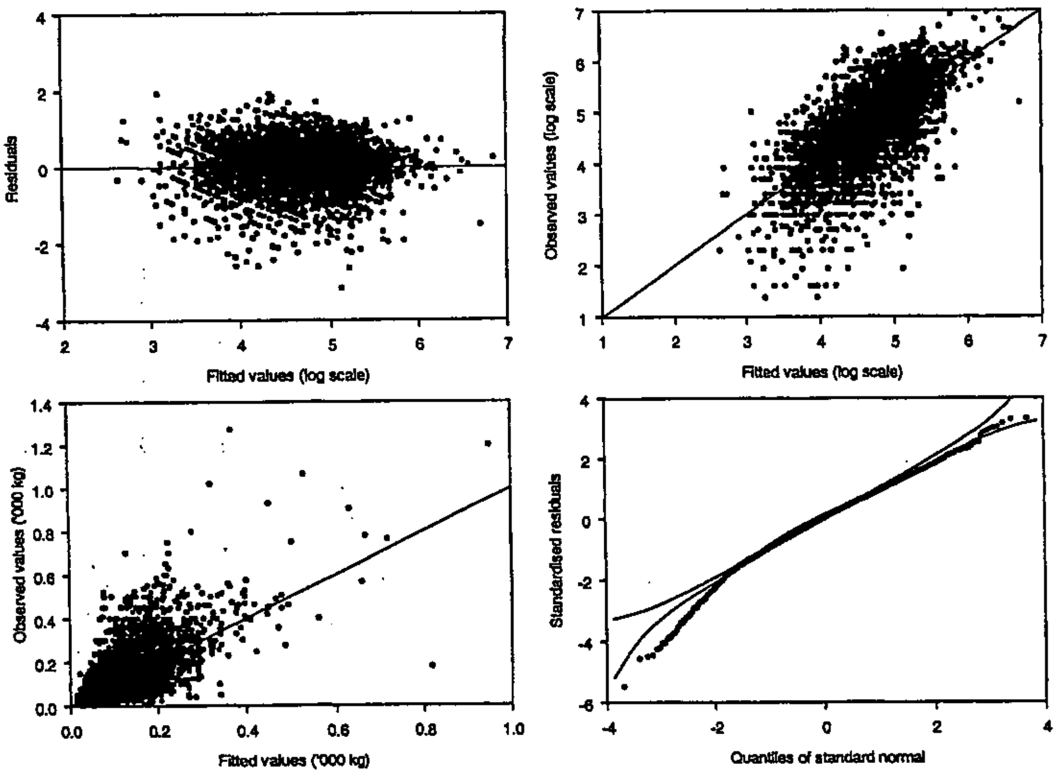

Figure B23: Residual diagnostic plots for the LFE CPUE model in ESA 20 for the years 1990–91 to 2001–02. Bottom right figure shows reference lines that are 95% confidence envelopes for a theoretical normal distribution.

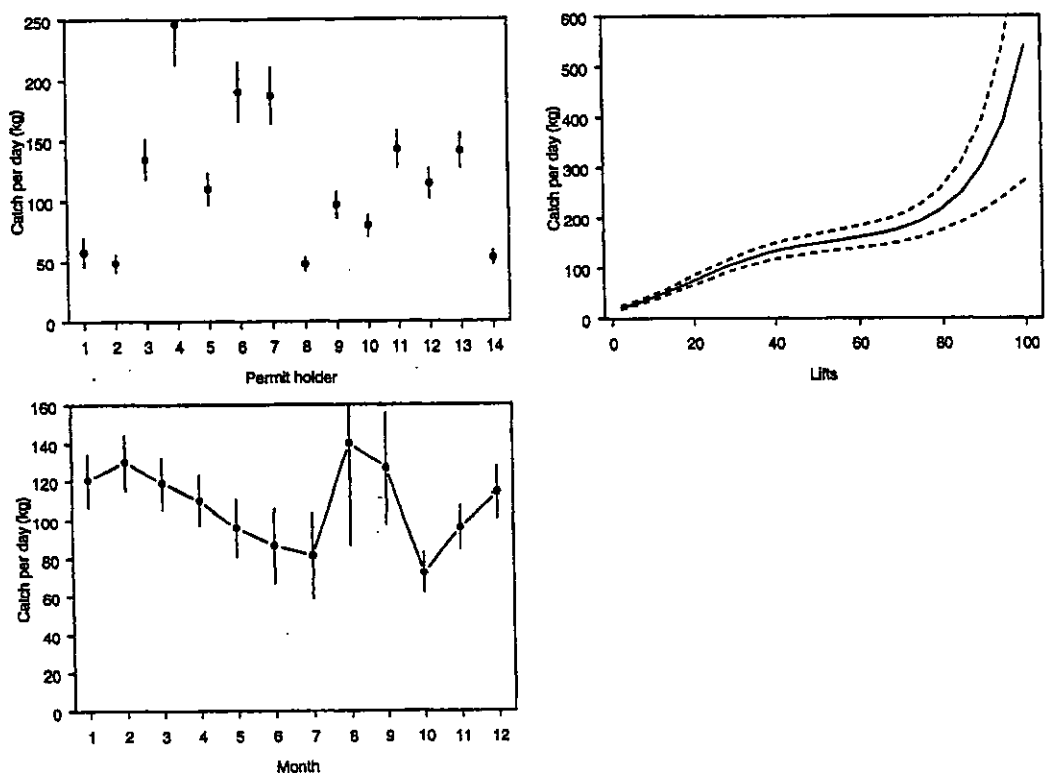

Figure B24: Expected catch rates (catch per day) for the LFE CPUE model in ESA 20 for the years 1990–91 to 2001–02, for the year, permit holder, lifts, and months variables. Bounds show the expected values ± 2 standard deviations.