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Tim Watson
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Tim Watson
Jeremy McKenzie
Bruce Hartill

NIWA
P O Box 109695
Newmarket
Auckland

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EXECUTIVE SUMMARY

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Unstandardised and standardised analyses of grey mullet CPUE data collected from the GMU 1 setnet fishery between 1989 and 2001 are presented. Analyses of the data revealed regional differences in annual CPUE trend. Evidence of annual CPUE decline was found in the Kaipara Harbour, the Manukau Harbour, and the Hauraki Gulf. The remaining regional zones, east Northland, North west coast, and Lower Waikato, showed a relatively flat trend.

1. INTRODUCTION

Grey mullet (*Mugil cephalus*) occurs widely throughout the world in sub-tropical and temperate latitudes. Grey mullet are detritivorous as they feed by filtering and sifting bottom sediments or surface ooze for organic material. In New Zealand, grey mullet mature at 3 to 4 years of age and may live to 12 years of age (Anon. 1989). Principal grey mullet habitats are slow-moving rivers, estuaries, and shallow coastal areas or embayments. Grey mullet occur around most of coastal New Zealand as far south as the Otago peninsula and attain the highest densities around the northern half of the North Island, of where 95% of the annual commercial harvest of grey mullet is taken (Annala & Sullivan 1997).

The northern grey mullet fishery (GMU 1) is managed as one discrete zone under a single annual commercial TAC. Most of the annual commercial catch of grey mullet from GMU 1 comes from the larger harbours and embayments - these being (on the west coast) the Manukau and Kaipara Harbours and (on the east coast) Rangunu Bay and the Firth of Thames. However, significant quantities of grey mullet are also taken from other North Island harbours and rivers.

The grey mullet fishery is worth about NZ$2–3 million per annum. Most of the catch is sold locally, principally as bait. The average annual commercial catch from GMU 1 over the last four fishing years has been about 800 tonnes. Annual commercial catches from GMU 1 have all been markedly lower than the annual TACs since the inception of the Quota Management System (QMS) in 1986 (Annala & Sullivan 1997). However, failure on the part of the commercial fishery to attain quota limits is not necessarily attributable to poor stock abundance. A profile of the commercial GMU 1 fishery by the Ministry of Fisheries in 1990 showed the available mullet quota was highly fragmented (McKenzie 1990): most of the annual under-catch was attributable to uneconomic (under 10 tonne) quota components.

Although grey mullet is not a major recreational species (Bradford 1996), by virtue of the habitats in which it is found it is a species of high 'social' value, particularly amongst Maori. To many northern Iwi the harbours and the rivers of the North Island are sacrosanct, the fish that live in these environments being regarded as an intrinsic part of them. Some Iwi believe many harbour and river fish stocks, including grey mullet, are in decline,and commonly cite environmental mismanagement and over-fishing as principal causes. In recent times, issues concerning the availability of grey mullet in the various North Island bays, harbours, and estuaries has been the cause of much sector group conflict.

Conflicts surrounding grey mullet have been exacerbated by a lack of definitive scientific knowledge regarding New Zealand grey mullet biology and ecology. Research on New Zealand grey mullet is limited to small-scale ageing and movement studies (Anon, 1989, Wells, 1976). More is known about the biology of grey mullet in other parts of the world, as it is an important aquaculture species in many countries. Regarding some of the more fundamental species characteristics such as growth, early life history, habitat use, and spawning cycles, New Zealand grey mullet is similar to grey mullet in other parts of the world. However, overseas research has limited applicability to New Zealand grey mullet. Virtually nothing is known of New Zealand grey mullet stock abundance, stock age structure, and stock integrity. Consequently, there is yet to be a viable stock assessment for New Zealand grey mullet. It is unknown whether current levels of exploitation will support Maximum Sustainable Yield (MSY) or move the stock toward MSY (Annala & Sullivan 1997).

An abundance index for the northern grey mullet stock would constitute a critical piece of information on which a stock assessment could be based. Commercial catch and effort data collected from the northern commercial grey mullet fishery between 1989 and 2000 may provide a viable index for the GMU 1 stock. This report presents both standardised and unstandardised analyses of commercial catch and effort data from GMU 1.

J. McKenzie (NIWA, Unpublished results) performed both unstandardised and standardised analyses of setnet CPUE data. The study indicated that trends in relative abundance of grey mullet were not the same over all areas of GMU 1 between 1983 and 1996. Abundance indices derived for east and west coast grey mullet fisheries were different. A decline in CPUE trend was seen in west coast data after 1990. However, no such decline in CPUE was evident in east coast data of the same period. As a further complication, the CPUE decline seen in the post 1990 west coast data was not seen in all west coast fishing areas. In particular, the decline in Manukau and Kaipara Harbour data was not seen in Lower Waikato River and Northern Coast data. However, as the majority of grey mullet caught on the west coast come for these two harbours, evidence that local scale abundance had declined was cause for concern.

The objective of this report is to update the above study to include all data from 1989 to 2002.

2. METHODS

2.1 CPUE data

All currently available data relating to targeting or catches of GMU (landing dates ranging from 31/7/89 to 29/7/03) were extracted from the Ministry of Fisheries Catch Effort Landing Return (CELR) database. Only CELR data were extracted, as previous studies have found pre-1989 Fisheries Statistics Unit (FSU) data to be of doubtful consistency with more recent data, given its summarised form. Late FSU and early CELR data are thought to be incomplete, as the transition between the two reporting systems was gradual.

These extracts yielded fishing effort data from 62 209 trips and grey mullet green weights from 60 105 trips. These data tables were linked via the common field "Trip_key" which is generated electronically in Ministry of Fisheries databases. An extract of all trips relating to set net effort yielded 40 998 records. Of these, 33 915 trips were associated with set net effort and grey mullet target only. The number of zero catch trips totalled 187 distributed across all years and all zones. It was therefore considered acceptable to remove these from the groomed data set. Finally, all part fishing year data were removed. The final data therefore came from the period 1/10/89 to 31/9/2002.

Records were sorted chronologically by vessel, and examined for errors given the recent reported fishing history. This approach highlighted an undesirable variety, and in for some vessels quantity, of errors. Where possible, these have been rectified, in the light of the fishing history, of the vessels concerned. Corrections for most apparent errors were usually, but not always obvious. There are likely to be many errors which went undetected during the grooming process, but these are less likely to result in misleading interpretation as they did not stand out as unusual, and may therefore be closer to the true value. Paul (2003) discussed the types of errors found in set net data.

In a small percentage of records, no estimate of net length was available. In such instances, the median value of recent estimates was used. Cursory examination of the reported number of sets per day, soak time, and mesh sizes used suggested that these data were not reliable due to both of the high proportion of missing values and the apparent inconsistency of those values which were recorded. Reported grey mullet green weights were also examined for potential errors in the light of estimated catches and the amount of fishing effort employed (as reported in the fishing effort table). Reported statistical areas were also groomed for errors given the recorded landing point and GMU fish stock. The final groomed data is seen in Table 1.

Table 1: Final groomed numbers of trips for each zone.

Fishing year	East Northland	Hauraki Gulf	Kaipara Harbour	Lower Waikato	Manukau Harbour	North West Coast	Zone Total
1989-90	780	254	875	144	615	189	2857
1990-91	902	219	889	108	570	188	2876
1991-92	834	169	916	167	439	236	2761
1992-93	713	103	786	67	456	156	2281
1993-94	666	77	750	75	503	269	2340
1994-95	725	76	881	136	282	276	2376
1995-96	720	113	815	140	401	177	2366
1996-97	576	84	793	278	253	162	2146
1997-98	660	105	1142	270	335	174	2686
1998-99	696	65	752	217	445	92	2267
1999-00	668	68	857	300	225	192	2310
2000-01	615	104	821	347	184	223	2294
2001-02	657	168	757	375	316	174	2447
Total	9212	1605	11034	2624	5024	2508	32007

2.1.1 Geographical zones

Data from both reporting series were stratified into six geographical zones by amalgamating statistical reporting areas (Figure 1). The six areas, chosen on the basis that they encompassed significant regions of grey mullet catch, were:

- Lower Waikato River and southern coastal harbours (Stat areas 41 & 42)
- Manukau Harbour (Stat area 43)
- Kaipara Harbour (Stat area 44)
- North west coast and Harbours (Stat areas 45, 46, & 47)
- east Northland (Stat areas 2 & 3)
- Hauraki Gulf (Stat areas 5, 6, & 7).

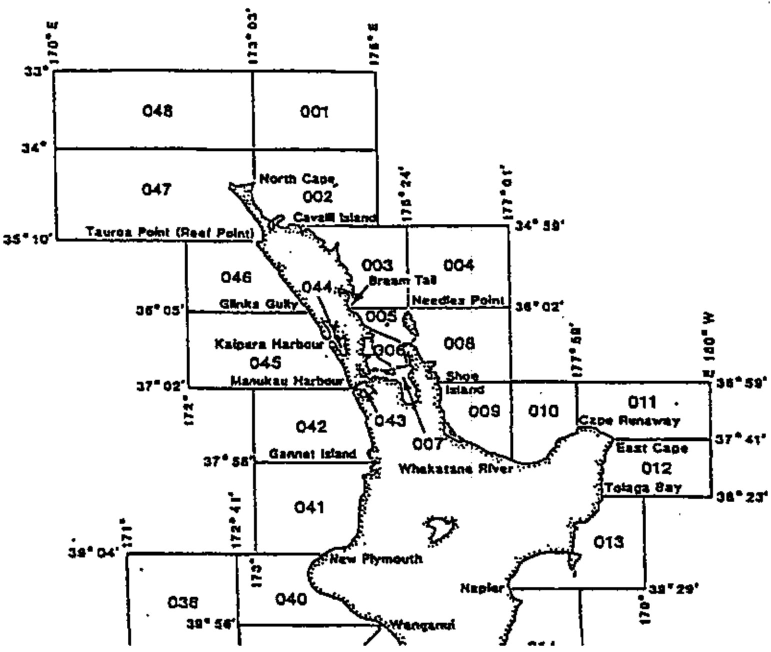


Figure 1: **Commercial grey mullet statistical reporting zones.**

2.1.2 Quarters

Data were further stratified into quarters based on the month of landing, as follows:

- Q1 - October, November, December
- Q2 – January, February, March
- Q3 – April, May, June
- Q4 – July, August, September.

2.1.3 Cumulative Trips

Vessel ID and number of landings were used to calculate the cumulative number of trips (cum.trips) that each vessel had. This was used as a proxy for the experience of the fisher/vessel. However, this approach has a number of problems. Firstly, vessels are not necessarily continuously operated by the same fisher over the period of time that data were collected. Secondly, there is no way of determining the experience of a fisher (vessel) before the start of the observational period (1989). All fishers must therefore start at zero trips in the first year, which is obviously incorrect.

The parameter "cum.trips" was entered into model as a continuous variable to examine any effects. However, due to the above problems, results were treated with caution.

2.2 Unstandardised analysis

Annual set net CPUE was investigated by using catch per metre net set (kg m^{-1}) data records for the period from 1989 to 2000. An unstandardised inspection of the data identified any trend by plotting raw trip green weights and CPUE values for each year.

2.3 Standardised analysis

Standardised investigations were undertaken by fitting log-linear models to the raw CPUE data. The log-linear modelling approach enabled explanatory variables other than year effects to be factored into the regression fits. Model coefficients derived for the year parameter were assumed representative of an abundance index (Doonan 1991, Vignaux 1992). The year parameter was always fitted as a categorical variable, as were most other parameters where a continuous relationship with CPUE could not be assumed (e.g., zone, quarter). It was assumed that cumulative trips had a continuous proportional relationship in that the more experienced a fisher, the higher the relative CPUE.

The process used to determine which parameters should be included into the log-linear fit to the data differs slightly from the stepwise procedure commonly applied in other New Zealand CPUE assessments (Vignaux 1992, 1993, Ballara 1997). The fitting procedure adopted for grey mullet CPUE included fitting interaction parameters as well as main effect parameters.

The effect of a significant interaction between the 'year' parameter with any other important parameter in the log-linear context essentially invalidates the index in relation to the 'year' parameter on its own. In simple terms, an interaction implies that a different year index exists at each level of the interaction parameter. For example if 'year' was found to interact significantly with 'zone' the implication would be that a different relative 'year' index is applicable to each 'zone'. The index derived from fitting a simple 'year' and 'zone' model to year/zone confounded data is likely to be 'zone' averaged. However, fitting the simple model ignoring the interaction term may well be the most appropriate analytical approach. A good mathematical fit does not necessarily imply biological reality. With regards to the above example, we should possibly be concerned only when there are grounds to believe the interaction between 'year' and 'area' has plausible biological foundation. If it does then the approach would be to fit a series of models relative to each 'area' subset of the data. Interaction terms commonly provide the best log-linear fits (high r-squared) to large 'noisy' (variable) data sets. However, interaction models tend to be more 'complex' than non-interaction models and therefore have greater latitude to conform to data variation. The general rule adopted in this report has been to ignore 'year' effect interactions unless they could be justified under plausible biological criteria. However, wherever such parameters were found to be significant they have been reported.

The stepwise approach used for this report to derive the appropriate log-linear model to fit to the CPUE data was as follows.

1. The data were split into east and west coast and each analysis was done independently.

2. A fully saturated model was first fitted to the data (all parameters all levels of interactions). This model gave the best possible r-squared fit to the data, and this r-squared value was used as the reference r-squared. Parameters and interactions which where not statistically significant were excluded from further model fits, as were all year interaction parameters regardless of statistical significance.

3. The full model was rerun with the exclusions listed above. A series of model fits were made to the data, with each parameter sequentially removed from the model. Interaction parameters that did not involve year were also included in this process. The reduction in the r-squared statistic, relative to the full model, was then calculated with each removal. A threshold of 2% was chosen for further removal from the model.

4. Fishing year indices were converted to their canonical form for the variance calculation in accordance to the methodologies given in Francis (1998).

2.4 Bayesian analysis

A Bayesian model, based upon the final chosen log-linear model of Step 3 above, was created and run using WinBugs (Spiegelhalter et al. 1996). WinBugs has been shown to be a useful tool for practical fisheries stock assessment (Meyer & Millar 1999). Log-linear models using WinBugs are discussed in detail by Congdon (2001) and an excellent review and example application of Bayesian methodology relating to stock assessment is also given by McAllister & Kirkwood (1998).

Bayesian modelling has several advantages, the main one of these is that the year effect is treated as a random parameter rather than a fixed but unknown one, as in a standard linear model (or GLM). Credibility intervals, analogous to confidence intervals, can be obtained that more accurately represent the underlying uncertainty relating to the parameter estimates, in the form of Monte Carlo Markov chains (MCMC). As well, known information can be included into the model as prior information. Such information may be based on previous or related studies, or industry knowledge.

For this model all priors were set to be uninformed and all initial values set to zero. The model is therefore governed by the data only and the parameter estimates should closely resemble those obtained in the standardised GLM analysis. The model code is given in Appendix B.

3. RESULTS

3.1 Unstandardised trend in setnet CPUE

Trip green weights were plotted over the length of the data set for both the east and the west coast to examine the overall catch (Figure 2). These data have been groomed and are therefore not the actual catch. However, they provide a very easy comparison between all the specified catch zones and can be assumed to be highly representative of the actual total catch.

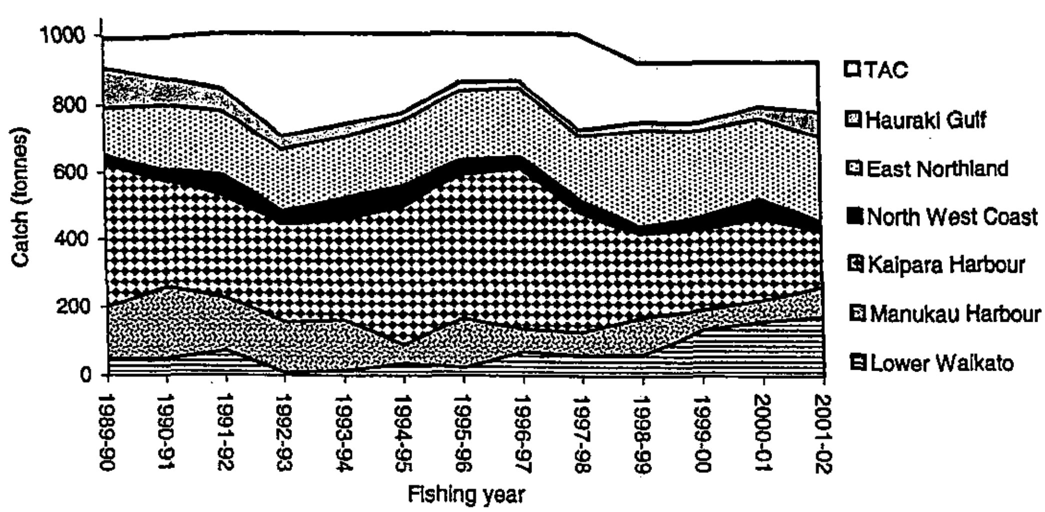


Figure 2: Recorded trip green weights in each zone (groomed data scaled to annual catch).

From Figure 2, it is clear that the total catch has varied from 700 to 900 with peaks in 1989–90 and 1996–97. However, the total catch has always been below the TAC. Another notable feature is the fluctuating catch in the Kaipara Harbour, the declining catch in the Manukau Harbour, and the increase in catch for the Lower Waikato and east Northland.

Using the full data series, CPUE was expressed as catch per unit metre set and plotted for 1989–2000 for the east and west coasts (Figure 3). Central trends relative to each data series are markedly disparate. The overall east coast CPUE displays a relatively flat trend, while the west coast, peaking in 1995-96, displays an overall decline. The observed pattern in the data was considered confirmation of the *a priori* decision to analyse each series separately. The plots also indicate both data series are highly variable and likely to be less informative in the raw state.

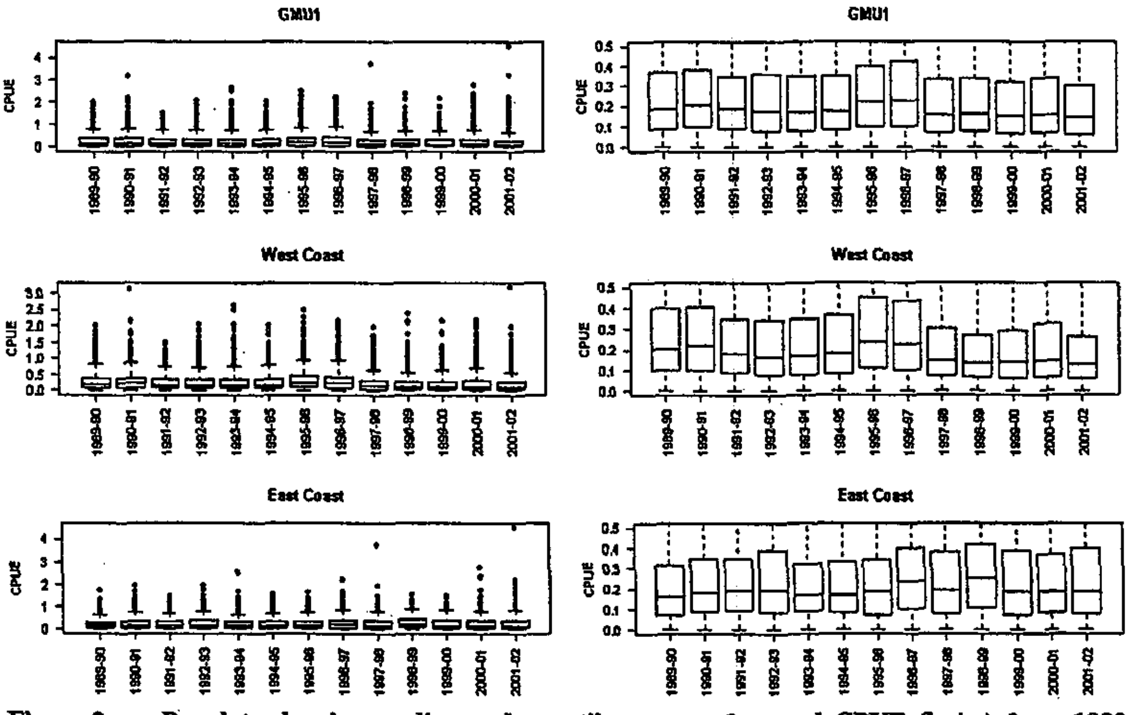


Figure 3: Boxplots showing median and quartile ranges of annual CPUE (kg/m) from 1989 to 2001. The plots on the right have a different y-axis scale.

Annual CPUE was also plotted by zone to assess the disparity amongst zones (Figure 4). There appears to be significant disparity amongst zones, particularly for the east coast zones. East Northland shows a steady increase in CPUE while the Hauraki Gulf shows a decrease. On the west coast, Kaipara Harbour shows a decline with a peak around 1996–97. The remaining zones show a relatively flat trend.

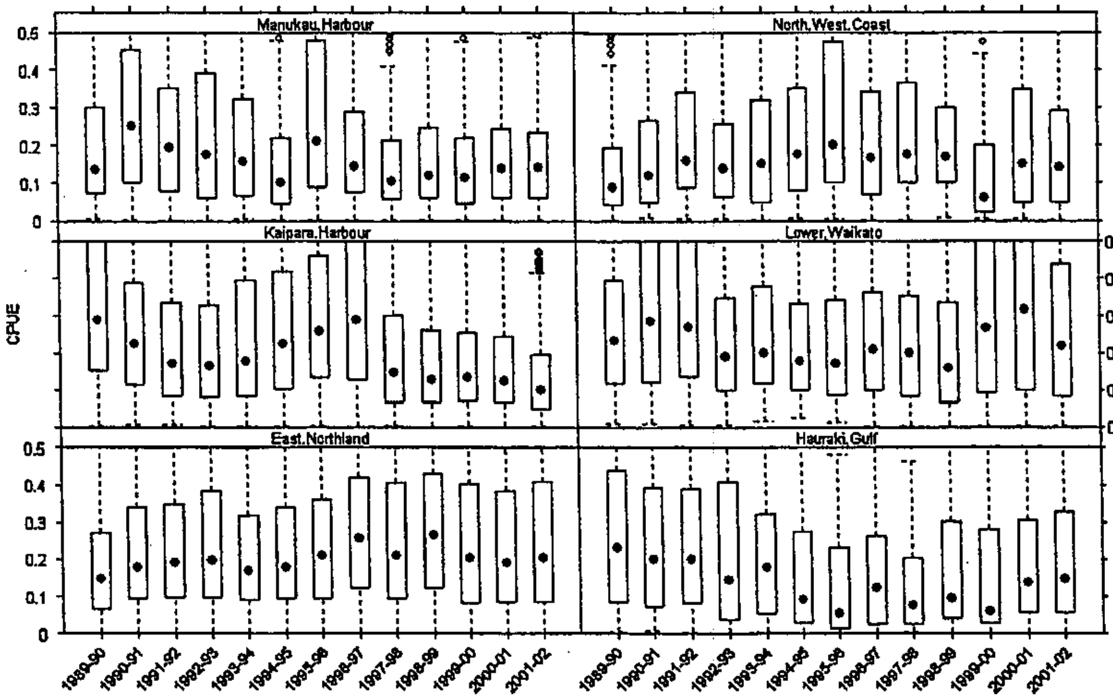


Figure 4: **Boxplot of CPUE (kg/m) for individual zones for both east and west coasts.**

3.2 Seasonal (quarter) effects

The raw data was examined for the effect that the quarter time period might have on the data. A Plot was done of CPUE per quarter for each zone (Figure 5). It can be seen that CPUE does vary between quarters. However, patterns are not consistent constant across all zones.

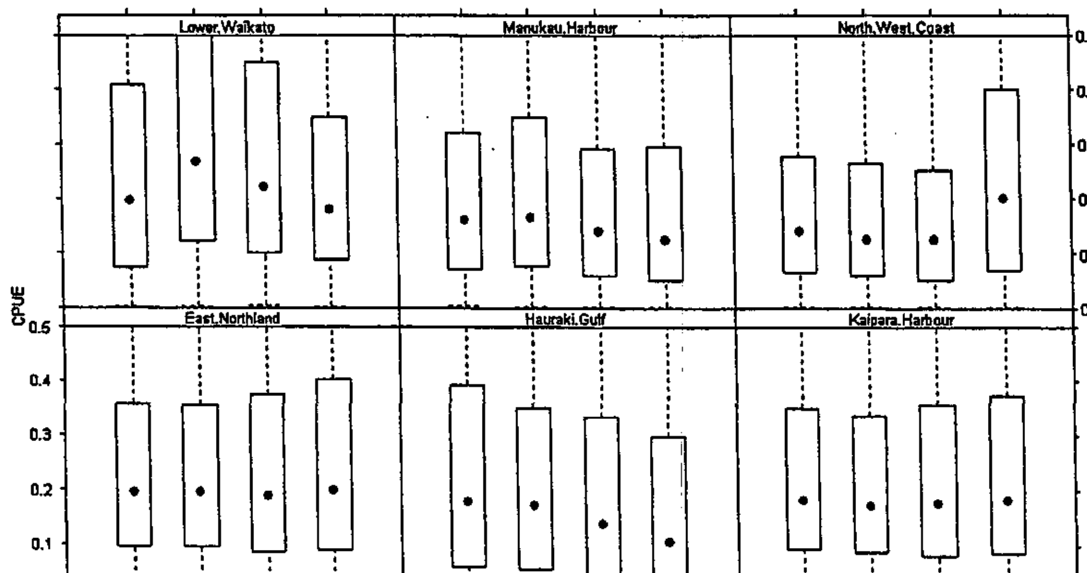


Figure 5: **Boxplots showing median and quartile ranges of CPUE (kg/m) per quarter for each of the six zones.**

3.3 Standardised trends in setnet CPUE

A series of standardised CPUE indices based the 1989–2000 CPUE data is given in Appendix A. Plots of the final CPUE indices are also given in Figure 6 (east coast) and 7 (west coast), and in Appendix A (figures 13–20).

Model fits to the combined data for both the east and west coasts (Appendix A – Table 2 & Table 3) produced highly significant year interactions with all three of the other parameters. The year/zone interaction was found to have the highest r-squared reduction. This means that this term has the greatest effect and explains the most variance. This leads to the conclusion that each zone has significantly different indices and supports previous evidence of disparity between zones (see Figure 3). A year/zone interaction term also has a plausible biological interpretation as the zones, particularly the harbours, are geographically separate. Further, the significant quarter interaction with zone also indicates that the quarter effect varies between zones.

The cumulative trips (cum.trips) effect and its interaction with all other parameters, including year, was found to be significant, although always estimated to be close to zero. This indicates that the cumulative trips data provides little informative power (i.e., exp(0)=1). The cumulative trips parameter and all its interaction terms were therefore removed from the final model. The CPUE index of the final model is given in Appendix A – Figure 13.

The R-squared statistic of all models is particularly low, indicating that the estimated model and related parameters explain very little of the variance in the data. The main conclusion from this is that there are significant other factors that are not included in this model or that the inherent variability is high.

The index derived from combined west coast data (Figure 6) depicts a significant annual decline that is not consistent across all years. The index declines from 1989 to 1993 before steadily increasing to a peak in 1996. It then rapidly decreases to an overall low point in 2000. No significant trend in CPUE indices is seen in the combined east coast data set, with the index being relatively constant throughout the time period.

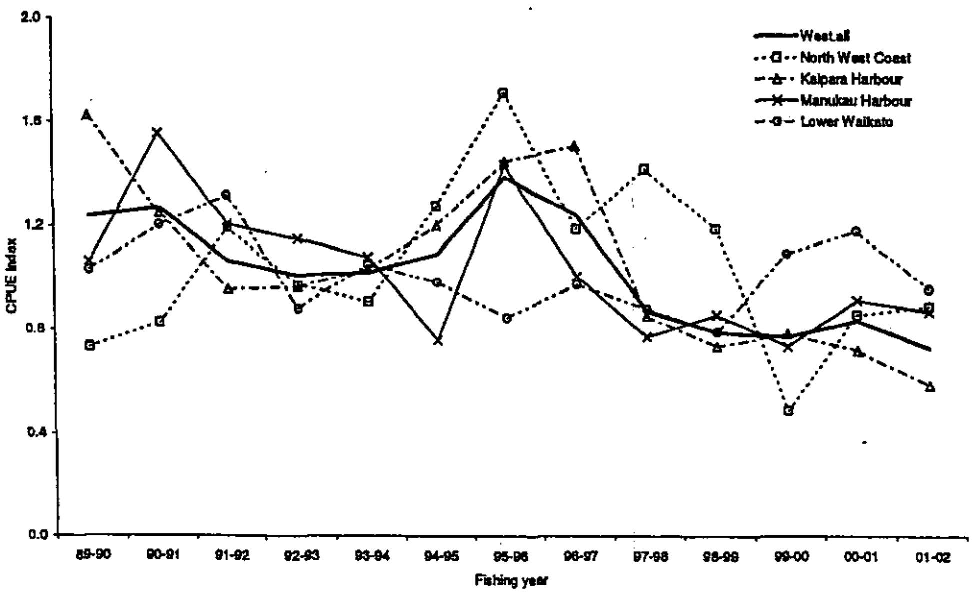


Figure 6: **CPUE index per year for west coast statistical areas.**

Separate analysis of the east coast data, East Northland and Hauraki Gulf, produced dramatic differences in the fishing-year indices (see Figure 7). East Northland produced no trend, and Hauraki Gulf displayed a significant and near continual decline.

For individual analysis of the west coast, CPUE indices decline in the Kaipara Harbour and Manukau Harbour (Figure 6). All zones, except Lower Waikato, peaked in 1996 before showing significant declines. Lower Waikato River shows a near constant trend.

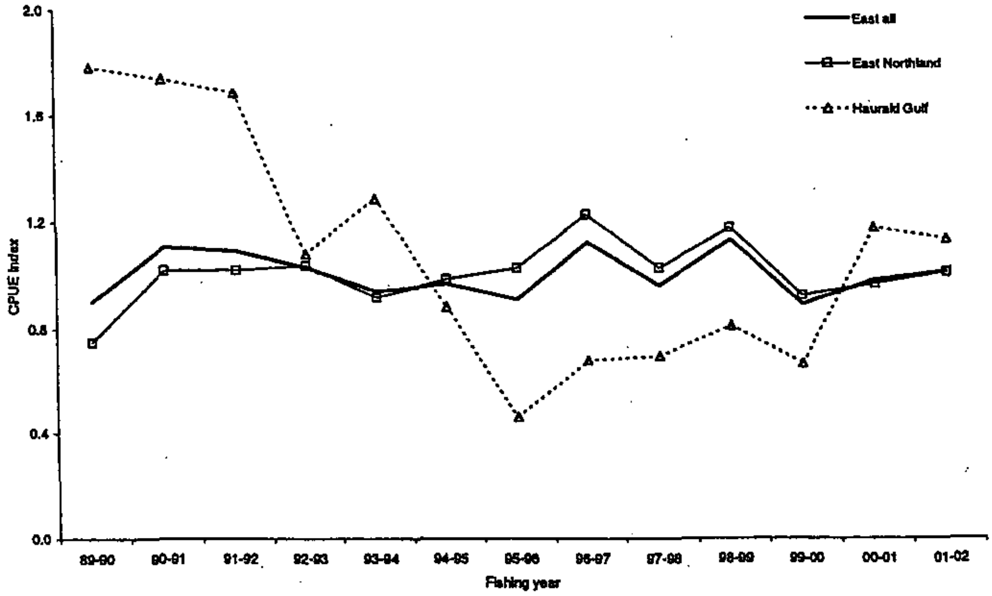


Figure 7: CPUE index per year for east coast statistical areas.

Plots are also given for the quarter effects for each zone (Figures 8 and 9). These plots show that that the quarter effect is different across each zone.

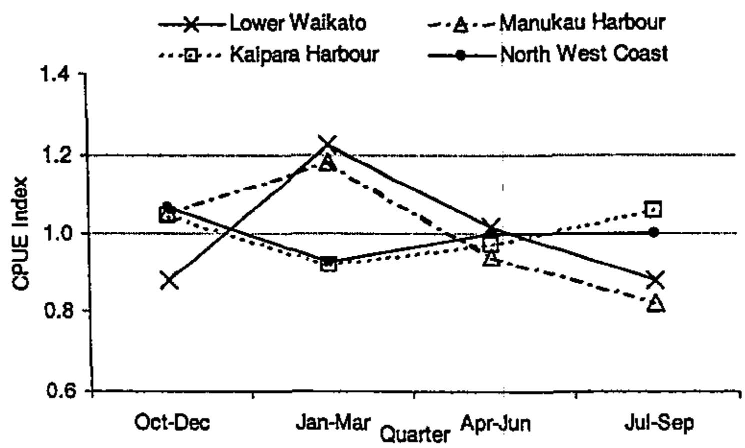


Figure 8: CPUE index per quarter for west coast statistical areas.

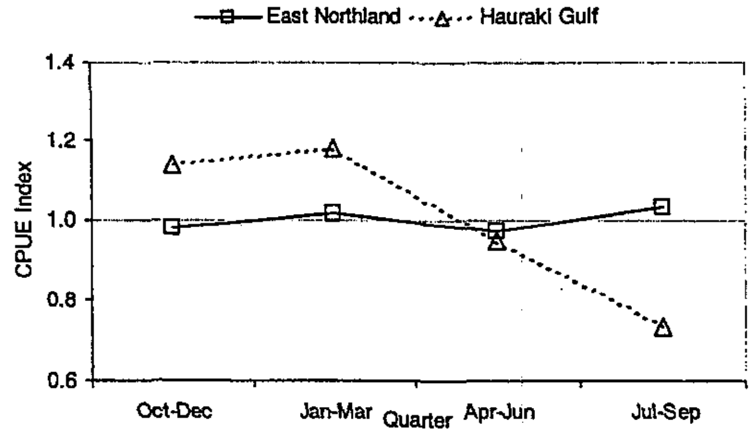
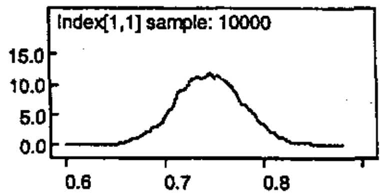


Figure 9: **CPUE index per quarter for east coast statistical areas.**

3.4 Bayesian model

A Bayesian model was created in WinBugs for comparison with the above analysis. The model was based on the final GLM model fitted in the above section for each individual zone. A diagram and code of the model used is given in Appendix B.

All priors were set to be uninformed and therefore the resulting estimates should approximately match those presented in Section 3.3. The model was run for 20 000 samples and visual inspection of the marginal posteriors indicated that the model converged quickly (e.g. Figure 10) and could therefore provide robust estimates of the parameters.



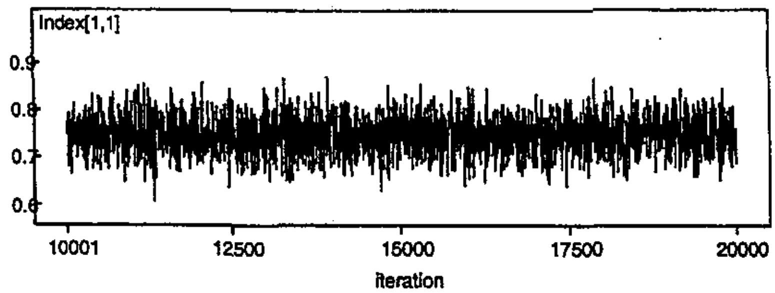


Figure 10: **Sampled density (left) and trace (right) of marginal posterior for east Northland CPUE index, 1989–90.**

As expected, the Bayesian results (Figures 11 and 12) match reasonably to the canonical results. In general, all of the expected values of the canonical results are contained within the 95% credibility intervals of the Bayesian model results. For the Hauraki Gulf and north west coast, where data are few, there are some considerable and systematic differences between the GLM indices and the posterior mean indices.

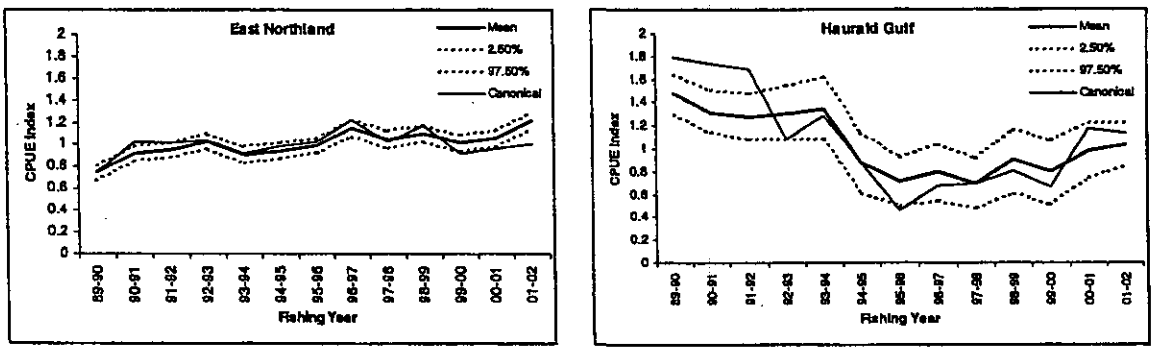


Figure 11: East coast Bayesian model CPUE index results compared to canonical results (estimated marginal posterior means and 95% CI sampled from MCMC with 10 000 burn in followed by 10 000 sample).

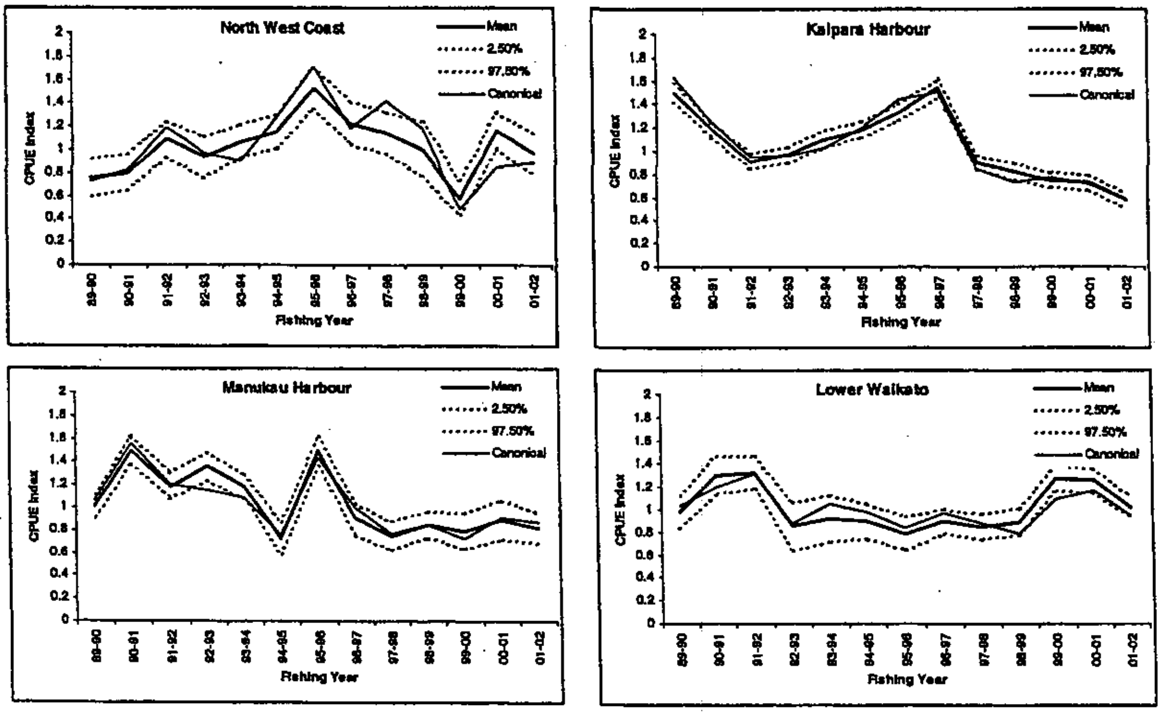


Figure 12 West coast Bayesian model CPUE index results compared to canonical results (estimated marginal posterior means and 95% CI sampled from MCMC with 10 000 burn in followed by 10 000 sample).

4. DISCUSSION

Both unstandardised and standardised analyses of setnet CPUE data indicate that trends in relative abundance of grey mullet between 1989 and 2002 were not the same over all areas of GMU 1. Abundance indices derived for east and west coast grey mullet fisheries were different. A decline in CPUE trend is seen in two out of four areas for the west coast data and one out of two for the east coast data for the same period. Although these declines are not mirrored over the entire data set, the declining pattern is particularly noticeable in the Manukau and Kaipara Harbours, areas where, historically, most of grey mullet is caught.

Grey mullet CPUE data from the west coast depict a statistically significant downward trend over the fishing years between 1989 and 2002. Although this index is unlikely to be truly representative of grey mullet abundance in all individual west coast fishing areas during the period, it may be reasonable to assume it provides a good approximation to abundance change in most of the west coast stock. If so, the index could be used in a stock assessment for the west coast region of GMU 1.

The east coast data show such disparity between zones that it may well be necessary to consider each zone separately. This is particularly important considering the marked decline of CPUE within the Hauraki Gulf.

Fisher experience is an intuitively nice concept. The more experienced a fisher is, the higher the CPUE compared to a less experienced fisher. However, as found in this study, it is very difficult to estimate the effect using current data and based on standard statistical analysis. Over the medium to long term the effect of changing boats, and the pre-start year (1989) experience, negate any apparent effect. However, some method of measuring experience may well improve the CPUE index estimates.

The low r-squared values for all models indicate that existing parameters do not explain the variance in the data to any high degree. This is of no great surprise as the final model includes only a year and quarter effect within each zone. The low r-squared value may indicate that other significant effects have not been included in this model. Fisher experience, as outlined above, is an example of such an unmodelled effect. Identification of other potential effects may well improve the overall predictive power of the model. However, it is doubtful that such data are available or in a form that can be readily used.

Canonical indices result in extremely small errors about the estimated values, because this approach assumes that the year indices are being treated as fixed effects, with variance related only to sampling error. Therefore, with a large sample, the confidence intervals on the estimated parameters are estimated to be very small. This may not reflect the true uncertainty.

The Bayesian analysis has several potential advantages over the standardised approach. Firstly, it is easy to set up and does not need canonical transformation of the results. Additionally, all parameters are assumed to be random and therefore the model calculates more plausible credibility intervals around the estimated parameters. One disadvantage of this approach is that the modeller must decide what effects should be included. It may well be the case, as demonstrated in the full model fit in the standardised approach, that many parameters are not significant and therefore need not be included in the final model. A stepwise model selection approach could be included within a Bayesian model (for an example, see Congdon, (2001)) although this could result in the model becoming very complex and cumbersome due to the amount of data in the model.

Another potential benefit of the Bayesian approach is the ability to include additional effects that are known to exist, but where little or no statistical data exists. The inclusion of currently un-modelled effects may well improve the overall predictive power of the model. Information relating to a previously unmodelled effect could be obtained from former/related studies and/or elicitation of industry knowledge.

5. CONCLUSIONS

- There is significant disparity in CPUE data amongst zones on both the east and west coasts. Stock abundance may therefore need to be treated on an individual zone basis.
- CPUE indices have declined in Hauraki Gulf, Manukau Harbour, Kaipara Harbour, and, since 1996, in the north west coast.
- The East Northland and Lower Waikato zones show little trend and appear to be relatively constant.

- Bayesian analysis of the data produced results similar to standard canonical analysis. This approach may provide more plausible estimates of the uncertainty, and should possibly be developed further in future studies.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Annala, J.H.; Sullivan K.J. (1997). Report from the Fishery Assessment Plenary, April-May 1997: stock assessment and yield estimates (Unpublished report held NIWA library, Wellington). 308 p.

Anon. (1989). Effects of Commercial Fishing on the Fisheries of the Manukau Harbour and Lower Waikato River (Unpublished report held in Ministry of Fisheries library, Auckland).

Ballara, S.L. (1997). Catch per unit effort analysis of ling (*Genypterus blacodes*): Chatham Rise bottom longline and Puysegur trawl fisheries, New Zealand Fisheries Assessment Research Document 97/17. 35 p.

Bradford, E., (1997). Marine recreational fishing survey 1993-94 in Ministry of Fisheries North Region, New Zealand Fisheries Assessment Research Document 97/7. 16 p.

Congdon, P. (2001). Bayesian statistical modelling, John Wiley & Sons, England.

Doonan, I. (1991). Orange rough fishery assessment, CPUE analysis – linear regression, NE Chatham Rise, New Zealand Fisheries Assessment Research Document 91/9. 43 p.

Francis, R.,I.,C.,C.,(1999). The impact of correlations is standardised CPUE indices, New Zealand Fisheries Assessment Research Document 99/42. 30 p.

McKenzie, J., (1990). Report on Under-Fishing of Grey Mullet (Mugil Cephalus) in Quota Management Area 1 (Unpublished report held Ministry of Fisheries Auckland). 7p.

Meyer, R.; Millar, R. (1999). BUGS in Bayesian stock assessments, *Canadian Journal of Fisheries and Aquatic Science. 56*: 1078–1086.

McAllister, M. K.; Kirkwood, G. P. (1998). Bayesian stock assessment: a review and example application using the logistic model. *ICES Journal of Marine Sciences. 55*: 1031–1060.

Paul, L.J.(2003). Characterisation of the commercial and recreational fisheries for rig (Mustelus lenticulatus) in northern New Zealand (SPO 1 and SPO 8), and unstandardised CPUE analyses of the targeted setnet fisheries. *New Zealand Fisheries Assessment Report 2003/22.* 69 p.

Speilgelhalter, D. J. et al. (1996). Bayesian Inference using Gibbs Sampling (BUGS). Medical Research Council Biostatistics Unit, Institute of Public Health, Cambridge, England.

Vignaux, M (1992). Catch per unit effort analysis of the hoki fishery. New Zealand Fisheries Assessment Research Document 92/14. 31 p.

Wells, R. (1976). The utilisation of the Lower Waikato Basin by the grey mullet, Mugil cephalus. Unpublished MSc thesis, University of Waikato. 57 p.

APPENDIX A

Table 2: Standardised analyses tables of grey mullet CPUE from the CELR series data for combined west coast.

West Coast Full Model Fit

	Df	Sum Sq	Mean Sq	F value	Pr(>F)		drop term RSS	% reduction in R^2
FYEAR	12.0	762.4	63.5	55.97	< 2.2e-16	***	24118.60	9.52%
cum.trips	1.0	141.2	141.2	124.38	< 2.2e-16	***	23891.90	0.17%
Quarter	3.0	23.0	7.7	6.76	0.00	***	23926.70	1.60%
Zone	3.0	386.3	128.8	113.43	< 2.2e-16	***	24068.20	7.44%
FYEAR:cum.trips	12.0	70.5	5.9	5.18	0.00	***	23960.80	3.01%
FYEAR:Quarter	36.0	323.4	9.0	7.91	< 2.2e-16	***	24175.90	11.89%
FYEAR:Zone	36.0	589.8	16.4	14.43	< 2.2e-16	***	24523.80	26.25%
cum.trips:Quarter	3.0	13.9	4.6	4.09	0.01	**	23893.90	0.25%
cum.trips:Zone	3.0	45.5	15.2	13.37	0.00	***	23935.50	1.96%
Quarter:Zone	9.0	213.7	23.7	20.91	< 2.2e-16	***	24101.50	8.82%
Residuals	21043.0	23887.9	1.1					

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Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-Squared: 0.1 Adjusted R-squared: 0.1

Non-year interaction model

	Df	Sum Sq	Mean Sq	F value	Pr(>F)		drop term RSS	% reduction in R^2
FYEAR	12.0	762.4	63.5	53.82	< 2.2e-16	***	25728.60	55.12%
cum.trips	1.0	141.2	141.2	119.61	< 2.2e-16	***	24951.00	0.76%
Quarter	3.0	23.0	7.7	6.50	0.00	***	24962.10	1.53%
Zone	3.0	386.3	128.8	109.08	< 2.2e-16	***	25026.70	6.05%
cum.trips:Quarter	3.0	8.1	2.7	2.29	0.08	.	24945.80	0.39%
cum.trips:Zone	3.0	30.7	10.2	8.68	0.00	***	24969.30	2.03%
Quarter:Zone	9.0	165.6	18.4	15.59	< 2.2e-16	***	25105.90	11.58%
Residuals	21127.0	24940.2	1.2					

Multiple R-Squared: 0.1 Adjusted R-squared: 0.1

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.5	0.0	-42.2	< 2e-16	***
FYEAR1990-91	0.0	0.0	0.8	0.41	
FYEAR1991-92	-0.1	0.0	-3.8	0.00	***
FYEAR1992-93	-0.2	0.0	-5.2	0.00	***
FYEAR1993-94	-0.2	0.0	-4.6	0.00	***
FYEAR1994-95	-0.1	0.0	-3.2	0.00	**
FYEAR1995-96	0.1	0.0	3.5	0.00	***
FYEAR1996-97	0.0	0.0	0.6	0.53	
FYEAR1997-98	-0.3	0.0	-9.2	< 2e-16	***
FYEAR1998-99	-0.4	0.0	-11.1	< 2e-16	***
FYEAR1999-00	-0.4	0.0	-11.9	< 2e-16	***
FYEAR2000-01	-0.4	0.0	-9.6	< 2e-16	***
FYEAR2001-02	-0.5	0.0	-13.4	< 2e-16	***
cum.trips	0.0	0.0	-3.0	0.00	**
QuarterQ2.Jan-Mar	-0.1	0.0	-2.4	0.01	*
QuarterQ3.Apr-Jun	-0.1	0.0	-2.7	0.01	**
QuarterQ4.Jul-Sep	0.0	0.0	0.1	0.90	
ZoneLower.Waikato	0.2	0.1	3.0	0.00	**
ZoneManukau.Harbour	-0.2	0.0	-5.7	0.00	***
ZoneNorth.West.Coast	-0.2	0.1	-4.6	0.00	***
cum.trips:QuarterQ2.Jan-Mar	0.0	0.0	-0.7	0.48	
cum.trips:QuarterQ3.Apr-Jun	0.0	0.0	1.1	0.27	
cum.trips:QuarterQ4.Jul-Sep	0.0	0.0	-0.7	0.47	
cum.trips:ZoneLower.Waikato	-0.1	0.0	-4.7	0.00	***
cum.trips:ZoneManukau.Harbour	0.0	0.0	0.9	0.37	
cum.trips:ZoneNorth.West.Coast	0.0	0.0	-0.8	0.41	
QuarterQ2.Jan-Mar:ZoneLower.Waikato	0.4	0.1	6.1	0.00	***
QuarterQ3.Apr-Jun:ZoneLower.Waikato	0.2	0.1	2.7	0.01	**
QuarterQ4.Jul-Sep:ZoneLower.Waikato	-0.1	0.1	-1.1	0.25	
QuarterQ2.Jan-Mar:ZoneManukau.Harbour	0.2	0.1	3.6	0.00	***
QuarterQ3.Apr-Jun:ZoneManukau.Harbour	-0.1	0.1	-1.0	0.31	
QuarterQ4.Jul-Sep:ZoneManukau.Harbour	-0.3	0.1	-4.8	0.00	***
QuarterQ2.Jan-Mar:ZoneNorth.West.Coast	0.0	0.1	0.0	0.99	
QuarterQ3.Apr-Jun:ZoneNorth.West.Coast	-0.1	0.1	-0.9	0.36	
QuarterQ4.Jul-Sep:ZoneNorth.West.Coast	0.2	0.1	2.5	0.01	*

Final Model

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12.0	752.5	62.7	52.53	< 2.2e-16	***
Quarter	3.0	24.0	8.0	6.70	0.00	***
Zone	3.0	426.2	142.1	119.01	< 2.2e-16	***
Quarter:Zone	9.0	180.5	20.1	16.80	< 2.2e-16	***
Residuals	21162.0	25263.9	1.2			

Multiple R-Squared: 0.1 Adjusted R-squared: 0.1
F-statistic: 42.91 on 27 and 21162 DF, p-value: < 2.2e-16

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.55	0.0	-44.2	< 2e-16	***
FYEAR1990-91	0.03	0.0	0.7	0.48	
FYEAR1991-92	-0.15	0.0	-4.1	0.00	***
FYEAR1992-93	-0.21	0.0	-5.4	0.00	***
FYEAR1993-94	-0.20	0.0	-5.2	0.00	***
FYEAR1994-95	-0.13	0.0	-3.3	0.00	***
FYEAR1995-96	0.12	0.0	3.0	0.00	**
FYEAR1996-97	0.00	0.0	0.0	0.96	
FYEAR1997-98	-0.35	0.0	-9.8	< 2e-16	***
FYEAR1998-99	-0.45	0.0	-11.8	< 2e-16	***
FYEAR1999-00	-0.48	0.0	-12.5	< 2e-16	***
FYEAR2000-01	-0.40	0.0	-10.5	< 2e-16	***
FYEAR2001-02	-0.53	0.0	-14.2	< 2e-16	***
QuarterQ2.Jan-Mar	-0.10	0.0	-2.7	0.01	**
QuarterQ3.Apr-Jun	-0.08	0.0	-2.5	0.01	*
QuarterQ4.Jul-Sep	0.00	0.0	0.0	0.98	
ZoneLower.Waikato	0.06	0.0	1.2	0.21	
ZoneManukau.Harbour	-0.21	0.0	-5.6	0.00	***
ZoneNorth.West.Coast	-0.31	0.1	-6.1	0.00	***
QuarterQ2.Jan-Mar:ZoneLower.Waikato	0.41	0.1	6.2	0.00	***
QuarterQ3.Apr-Jun:ZoneLower.Waikato	0.20	0.1	2.8	0.01	**
QuarterQ4.Jul-Sep:ZoneLower.Waikato	-0.06	0.1	-0.8	0.42	
QuarterQ2.Jan-Mar:ZoneManukau.Harbour	0.19	0.1	3.6	0.00	***
QuarterQ3.Apr-Jun:ZoneManukau.Harbour	-0.06	0.1	-1.1	0.27	
QuarterQ4.Jul-Sep:ZoneManukau.Harbour	-0.26	0.1	-4.8	0.00	***
QuarterQ2.Jan-Mar:ZoneNorth.West.Coast	-0.02	0.1	-0.3	0.79	
QuarterQ3.Apr-Jun:ZoneNorth.West.Coast	-0.02	0.1	-0.3	0.80	
QuarterQ4.Jul-Sep:ZoneNorth.West.Coast	0.21	0.1	3.2	0.001547	**

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	1.297	1.174	1.236	0.025
90-91	1.332	1.204	1.268	0.025
91-92	1.115	1.008	1.062	0.025
92-93	1.059	0.949	1.004	0.027
93-94	1.069	0.961	1.015	0.026
94-95	1.147	1.032	1.090	0.027
95-96	1.461	1.313	1.387	0.027
96-97	1.305	1.170	1.238	0.027
97-98	0.911	0.827	0.869	0.024
98-99	0.830	0.744	0.787	0.027
99-00	0.809	0.727	0.768	0.027
00-01	0.873	0.785	0.829	0.027
01-02	0.762	0.686	0.724	0.026

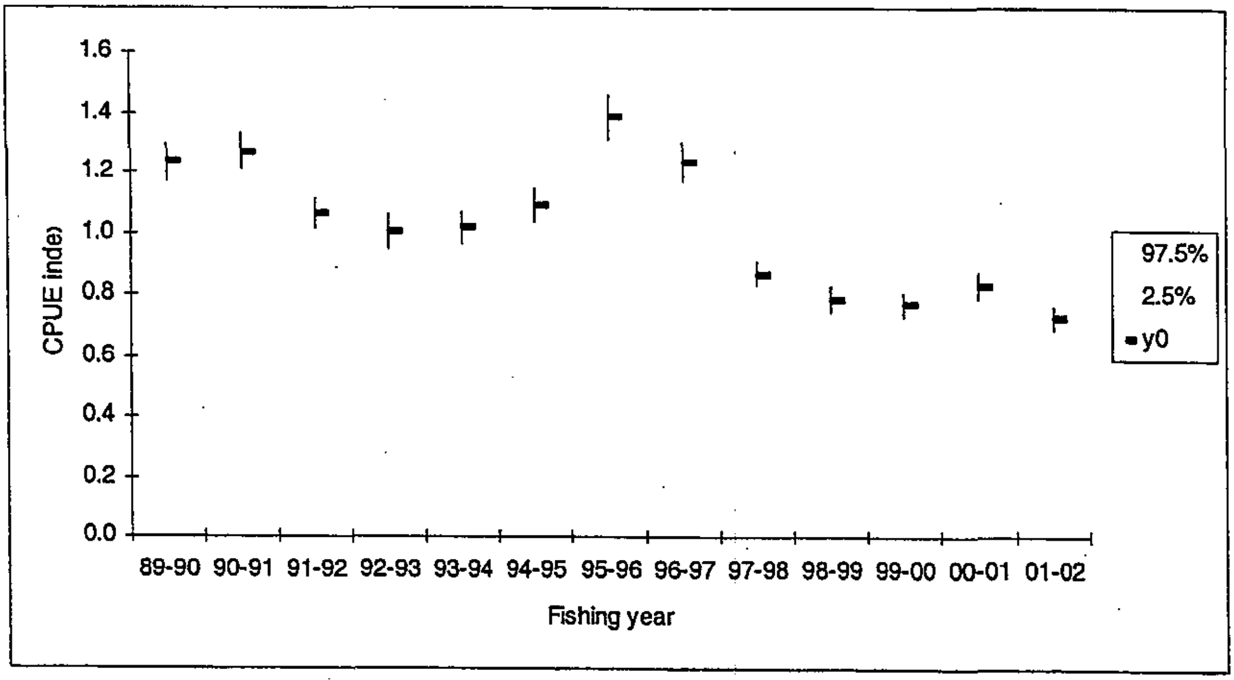

Figure 13: Canonical CPUE index for west coast combined (mean and 95% confidence intervals).

Table 3: Standardised analyses tables of grey mullet CPUE from the CELR series data for combined east coast.

Full Model Fit

	Df	Sum Sq	Mean Sq	F value	Pr(>F)		drop term RSS	% reduction in R^2
FYEAR	12.00	74.60	6.20	4.64	0.00	***	14484.80	7.86%
cum.trips	1.00	448.70	448.70	335.06	< 2.2e-16	***	14435.20	4.50%
Quarter	3.00	13.20	4.40	3.28	0.02	*	14382.70	0.94%
Zone	1.00	157.70	157.70	117.73	< 2.2e-16	***	14391.10	1.51%
FYEAR:cum.trips	12.00	367.10	30.60	22.84	< 2.2e-16	***	14700.70	22.49%
FYEAR:Quarter	36.00	150.60	4.20	3.12	0.00	***	14515.00	9.91%
FYEAR:Zone	12.00	349.90	29.20	21.77	< 2.2e-16	***	14719.00	23.73%
cum.trips:Quarter	3.00	13.10	4.40	3.26	0.02	*	14381.80	0.88%
cum.trips:Zone	1.00	26.40	26.40	19.73	0.00	***	14394.10	1.71%
Quarter:Zone	3.00	43.60	14.50	10.85	0.00	***	14412.30	2.95%
Residuals	10729.00	14368.80	1.30					

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Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-Squared: 0.10 Adjusted R-squared: 0.10

Non-year interaction model

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)		drop term RSS	% reduction in R^2
FYEAR	12.00	74.60	6.20	4.40	0.00	***	15301.80	11.11%
cum.trips	1.00	448.70	448.70	318.13	< 2.2e-16	***	15397.20	23.72%
Quarter	3.00	13.20	4.40	3.12	0.02	*	15221.20	0.45%
Zone	1.00	157.70	157.70	111.78	< 2.2e-16	***	15236.70	2.50%
cum.trips:Quarter	3.00	14.40	4.80	3.41	0.02	*	15230.90	1.73%
cum.trips:Zone	1.00	32.20	32.20	22.81	0.00	***	15249.10	4.14%
Quarter:Zone	3.00	55.10	18.40	13.02	0.00	***	15272.90	7.29%
Residuals	10789.00	15217.80	1.40					

Multiple R-Squared: 0.05 Adjusted R-squared: 0.05

Coefficients

	Estimate	Std. Error	t value	Pr(>|t|)		Exp(y)
(Intercept)	-1.70	0.05	-34.63	< 2e-16	***	0.18
FYEAR1990-91	0.22	0.05	4.19	0.00	***	1.24
FYEAR1991-92	0.23	0.05	4.42	0.00	***	1.26
FYEAR1992-93	0.19	0.06	3.33	0.00	***	1.20
FYEAR1993-94	0.07	0.06	1.20	0.23		1.07
FYEAR1994-95	0.09	0.06	1.68	0.09	.	1.10
FYEAR1995-96	0.03	0.06	0.59	0.55		1.03
FYEAR1996-97	0.28	0.06	4.66	0.00	***	1.32
FYEAR1997-98	0.11	0.06	2.02	0.04	*	1.12
FYEAR1998-99	0.29	0.06	5.06	0.00	***	1.34
FYEAR1999-00	0.12	0.06	2.00	0.05	*	1.12
FYEAR2000-01	0.17	0.06	2.92	0.00	**	1.19
FYEAR2001-02	0.20	0.06	3.62	0.00	***	1.22
cum.trips	-0.16	0.01	-11.28	< 2e-16	***	0.85
QuarterQ2.Jan-Mar	-0.05	0.05	-1.16	0.25		0.95
QuarterQ3.Apr-Jun	-0.02	0.05	-0.48	0.63		0.98
QuarterQ4.Jul-Sep	0.02	0.05	0.35	0.73		1.02
ZoneHauraki.Gulf	-0.28	0.08	-3.67	0.00	***	0.76
cum.trips:QuarterQ2.Jan-Mar	0.05	0.02	2.73	0.01	**	1.06
cum.trips:QuarterQ3.Apr-Jun	0.01	0.02	0.27	0.79		1.01
cum.trips:QuarterQ4.Jul-Sep	0.02	0.02	0.92	0.36		1.02
cum.trips:ZoneHauraki.Gulf	0.09	0.02	4.71	0.00	***	1.09
QuarterQ2.Jan-Mar:ZoneHauraki.Gulf	-0.08	0.09	-0.84	0.40		
QuarterQ3.Apr-Jun:ZoneHauraki.Gulf	-0.23	0.09	-2.49	0.01	*	0.80
QuarterQ4.Jul-Sep:ZoneHauraki.Gulf	-0.55	0.10	-5.70	0.00	***	0.57

Final Model

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12.00	74.80	6.20	4.28	0.00	***
Zone	1.00	166.50	166.50	114.43	< 2.2e-16	***
Zone:Quarter	6.00	64.00	10.70	7.34	0.00	***
Residuals	10797.00	15709.60	1.50			

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.91	0.04	-42.86	< 2e-16	***
FYEAR1990-91	0.21	0.05	3.94	0.00	***
FYEAR1991-92	0.19	0.05	3.56	0.00	***
FYEAR1992-93	0.13	0.06	2.32	0.02	*
FYEAR1993-94	0.04	0.06	0.73	0.47	
FYEAR1994-95	0.07	0.06	1.23	0.22	
FYEAR1995-96	0.01	0.06	0.14	0.89	
FYEAR1996-97	0.22	0.06	3.64	0.00	***
FYEAR1997-98	0.06	0.06	1.11	0.27	
FYEAR1998-99	0.23	0.06	3.89	0.00	***
FYEAR1999-00	-0.01	0.06	-0.23	0.82	
FYEAR2000-01	0.08	0.06	1.45	0.15	
FYEAR2001-02	0.11	0.06	2.02	0.04	*
ZoneHauraki.Gulf	-0.14	0.07	-1.99	0.05	*
ZoneEast.Northland:QuarterQ2.Jan-Mar	0.03	0.03	0.91	0.36	
ZoneHauraki.Gulf:QuarterQ2.Jan-Mar	-0.04	0.09	-0.42	0.68	
ZoneEast.Northland:QuarterQ3.Apr-Jun	-0.02	0.04	-0.58	0.56	
ZoneHauraki.Gulf:QuarterQ3.Apr-Jun	-0.24	0.09	-2.82	0.00	**
ZoneEast.Northland:QuarterQ4.Jul-Sep	0.05	0.04	1.32	0.19	
ZoneHauraki.Gulf:QuarterQ4.Jul-Sep	-0.50	0.09	-5.47	0.00	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.206 on 10797 degrees of freedom
Multiple R-Squared: 0.01906, Adjusted R-squared: 0.01734
F-statistic: 11.04 on 19 and 10797 DF, p-value: < 2.2e-16

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	0.968	0.836	0.902	0.037
90-91	1.185	1.029	1.107	0.035
91-92	1.172	1.011	1.091	0.037
92-93	1.112	0.945	1.029	0.041
93-94	1.021	0.861	0.941	0.042
94-95	1.047	0.888	0.968	0.041
95-96	0.982	0.836	0.909	0.040
96-97	1.224	1.023	1.123	0.045
97-98	1.042	0.881	0.961	0.042
98-99	1.225	1.035	1.130	0.042
99-00	0.966	0.814	0.890	0.043
00-01	1.066	0.897	0.982	0.043
01-02	1.092	0.929	1.010	0.040

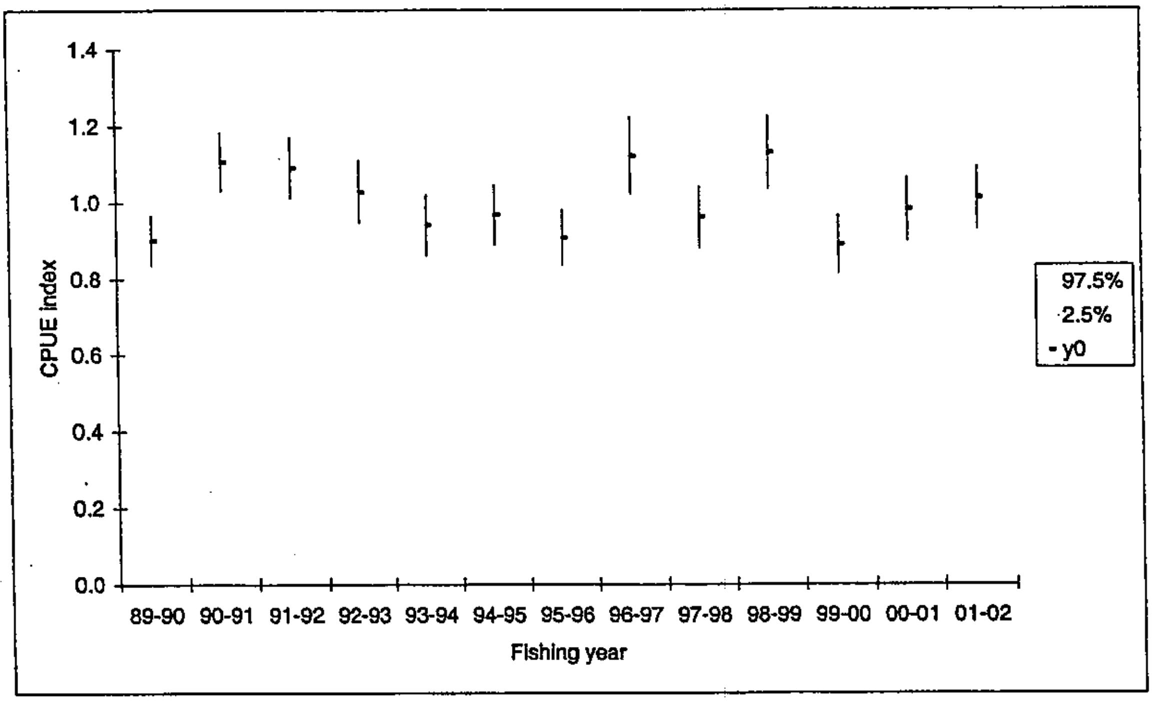

Figure 14: Canonical CPUE Index for east coast combined (mean and 95% confidence intervals).

Table 4: Standardised analyses tables of Grey Mullet CPUE from the CELR series data for Lower Waikato River and southern coastal harbours.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	1.20E+01	5.90E+01	4.92	4.15E+00	1.77E-06	***
Quarter	3.00E+00	5.53E+01	18.43	1.55E+01	5.09E-10	***
Residuals	2608.00	3.09E+03	1.19			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.7613	0.0963	-18.2950	< 2e-16	***
FYEAR1990-91	0.1569	0.1389	1.1300	0.2587	
FYEAR1991-92	0.2476	0.1244	1.9900	0.0467	*
FYEAR1992-93	-0.1565	0.1623	-0.9650	0.3347	
FYEAR1993-94	0.0174	0.1561	0.1120	0.9110	
FYEAR1994-95	-0.0512	0.1322	-0.3880	0.6983	
FYEAR1995-96	-0.1985	0.1300	-1.5280	0.1267	
FYEAR1996-97	-0.0609	0.1119	-0.5440	0.5864	
FYEAR1997-98	-0.1599	0.1131	-1.4140	0.1575	
FYEAR1998-99	-0.2666	0.1176	-2.2660	0.0235	*
FYEAR1999-00	0.0571	0.1105	0.5170	0.6052	
FYEAR2000-01	0.1337	0.1081	1.2370	0.2163	
FYEAR2001-02	-0.0799	0.1070	-0.7460	0.4555	
QuarterQ2.Jan-Mar	0.3327	0.0546	6.0920	0.0000	***
QuarterQ3.Apr-Jun	0.1482	0.0640	2.3150	0.0207	*
QuarterQ4.Jul-Sep	0.0023	0.0630	0.0360	0.9712	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.089 on 2608 degrees of freedom
Multiple R-Squared: 0.03565, Adjusted R-squared: 0.03011
F-statistic: 6.428 on 15 and 2608 DF, p-value: 1.191e-13

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	1.208	0.848	1.028	0.088
90-91	1.443	0.963	1.203	0.100
91-92	1.531	1.103	1.317	0.081
92-93	1.099	0.659	0.879	0.125
93-94	1.294	0.798	1.046	0.119
94-95	1.153	0.800	0.977	0.090
95-96	0.992	0.694	0.843	0.088
96-97	1.093	0.841	0.967	0.065
97-98	0.992	0.761	0.876	0.066
98-99	0.901	0.674	0.788	0.072
99-00	1.226	0.951	1.089	0.063
00-01	1.315	1.036	1.175	0.059
01-02	1.058	0.840	0.949	0.057

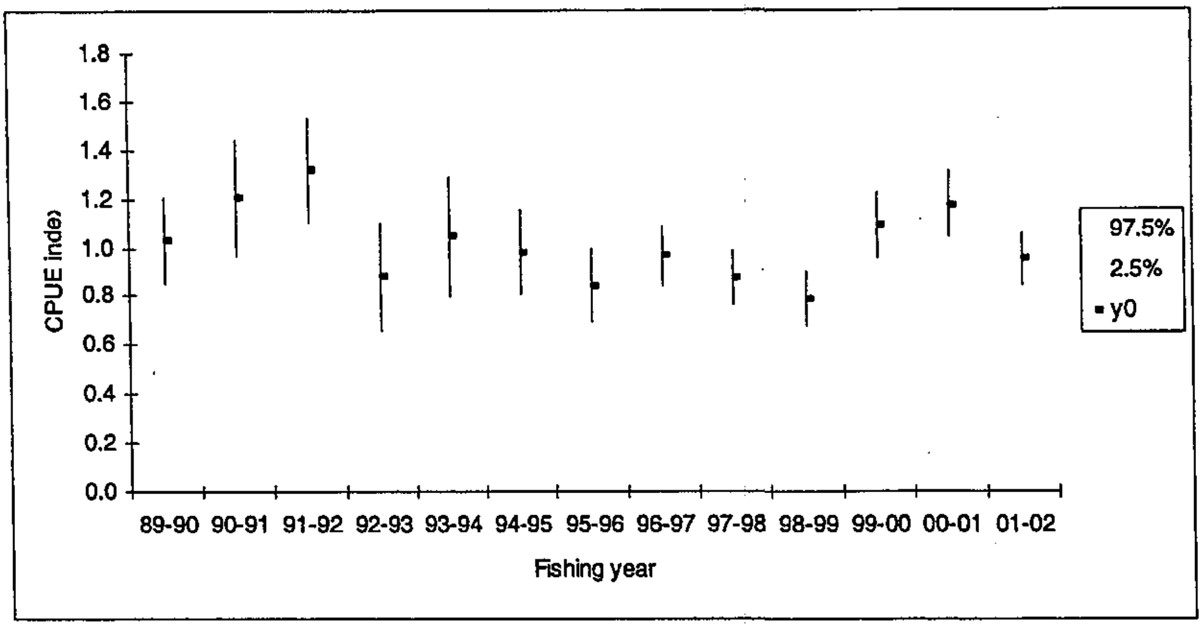

Figure 15: Canonical CPUE Index for Lower Waikato (mean and 95% confidence intervals).

Table 5: Standardised analyses tables of Grey Mullet CPUE from the CELR series data for Manukau Harbour.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12	269.2	22.4	18.179	< 2.2e-16	***
Quarter	3	84.8	28.3	22.921	9.85E-15	***
Residuals	5008	6178.9	1.2			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.93723	0.05113	-37.89	< 2e-16	***
FYEAR1990-91	0.38086	0.0648	5.877	4.44E-09	***
FYEAR1991-92	0.12683	0.06963	1.821	0.06861	
FYEAR1992-93	0.07859	0.0688	1.142	2.53E-01	
FYEAR1993-94	0.01533	0.06695	0.229	8.19E-01	
FYEAR1994-95	-0.33806	0.07991	-4.231	2.37E-05	***
FYEAR1995-96	0.29947	0.07137	4.196	2.77E-05	***
FYEAR1996-97	-0.05926	0.08301	-0.714	0.47536	
FYEAR1997-98	-0.3211	0.07555	-4.25	2.17E-05	***
FYEAR1998-99	-0.21789	0.06916	-3.151	0.00164	**
FYEAR1999-00	-0.37216	0.08664	-4.295	1.78E-05	***
FYEAR2000-01	-0.15652	0.09353	-1.673	0.09429	.
FYEAR2001-02	-0.20461	0.07699	-2.658	0.0079	**
QuarterQ2.Jan-Mar	0.11208	0.03889	2.882	3.96E-03	**
QuarterQ3.Apr-Jun	-0.11604	0.04772	-2.432	1.51E-02	*
QuarterQ4.Jul-Sep	-0.25439	0.0467	-5.447	5.35E-08	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.111 on 5008 degrees of freedom
Multiple R-Squared: 0.05419, Adjusted R-squared: 0.05135
F-statistic: 19.13 on 15 and 5008 DF, p-value: < 2.2e-16

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	1.155	0.966	1.061	0.045
90-91	1.696	1.410	1.553	0.046
91-92	1.329	1.080	1.204	0.052
92-93	1.264	1.031	1.148	0.051
93-94	1.182	0.973	1.077	0.049
94-95	0.852	0.661	0.757	0.063
95-96	1.585	1.277	1.431	0.054
96-97	1.133	0.867	1.000	0.066
97-98	0.859	0.680	0.770	0.058
98-99	0.941	0.766	0.853	0.051
99-00	0.834	0.629	0.731	0.070
00-01	1.047	0.767	0.907	0.077
01-02	0.968	0.761	0.865	0.060

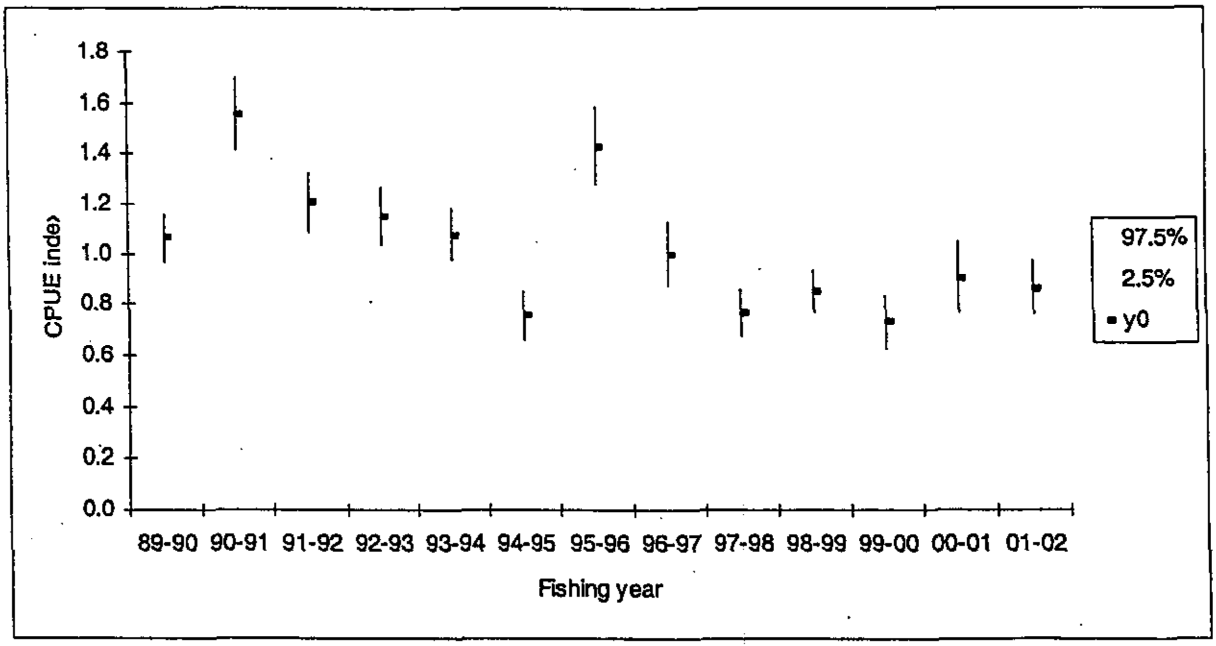

Figure 16: Canonical CPUE Index for Manukau Harbour (mean and 95% confidence intervals).

Table 6: Standardised analyses tables of Grey Mullet CPUE from the CELR series data for Kaipara Harbour.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12	965.9	80.5	74.1144	< 2.2e-16	***
Quarter	3	30	10	9.1929	4.52E-06	***
Residuals	11018	11965.6	1.1			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.27715	0.04098	-31.165	< 2e-16	***
FYEAR1990-91	-0.2623	0.04969	-5.279	1.33E-07	***
FYEAR1991-92	-0.53687	0.04936	-10.878	< 2e-16	***
FYEAR1992-93	-0.52729	0.05128	-10.282	< 2e-16	***
FYEAR1993-94	-0.45652	0.05196	-8.785	< 2e-16	***
FYEAR1994-95	-0.30304	0.04982	-6.083	1.22E-09	***
FYEAR1995-96	-0.1172	0.0509	-2.302	2.13E-02	*
FYEAR1996-97	-0.07666	0.05116	-1.498	0.13409	
FYEAR1997-98	-0.64772	0.047	-13.78	< 2e-16	***
FYEAR1998-99	-0.79618	0.05199	-15.315	< 2e-16	***
FYEAR1999-00	-0.73345	0.05031	-14.577	< 2e-16	***
FYEAR2000-01	-0.82006	0.0508	-16.144	< 2e-16	***
FYEAR2001-02	-1.0257	0.05203	-19.715	< 2e-16	***
QuarterQ2.Jan-Mar	-0.12691	0.03554	-3.571	3.57E-04	***
QuarterQ3.Apr-Jun	-0.07303	0.03149	-2.319	0.020402	*
QuarterQ4.Jul-Sep	0.01199	0.02843	0.422	0.673088	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.042 on 11018 degrees of freedom
Multiple R-Squared: 0.07683, Adjusted R-squared: 0.07557
F-statistic: 61.13 on 15 and 11018 DF, p-value: < 2.2e-16

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	1.735	1.513	1.624	0.034
90-91	1.333	1.165	1.249	0.034
91-92	1.012	0.886	0.949	0.033
92-93	1.027	0.890	0.958	0.036
93-94	1.104	0.954	1.029	0.036
94-95	1.280	1.118	1.199	0.034
95-96	1.546	1.343	1.444	0.035
96-97	1.611	1.397	1.504	0.036
97-98	0.901	0.799	0.850	0.030
98-99	0.786	0.679	0.732	0.036
99-00	0.833	0.726	0.780	0.034
00-01	0.765	0.665	0.715	0.035
01-02	0.625	0.540	0.582	0.036

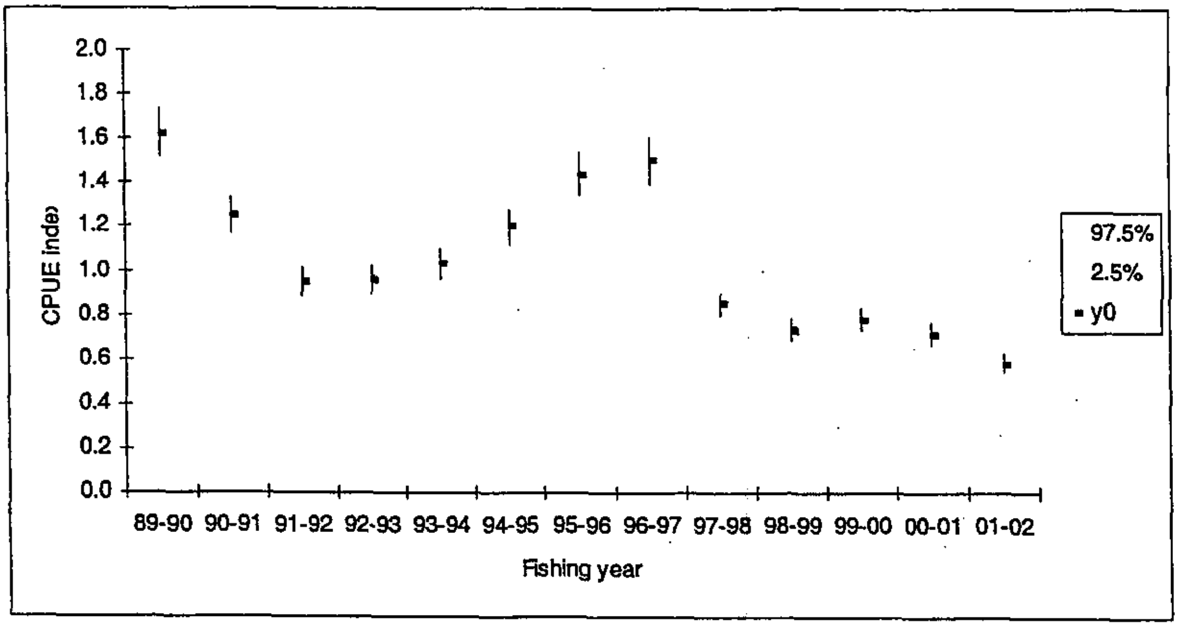

Figure 17: Canonical CPUE Index for Kaipara Harbour (mean and 95% confidence intervals).

Table 7: Standardised analyses tables of Grey Mullet CPUE from the CELR series data for North west coast and harbours.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12	214.9	17.9	13.28	< 2e-16	***
Quarter	3	63.5	21.2	15.698	4.10E-10	***
Residuals	2492	3360.1	1.3			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-2.38515	0.096	-24.845	< 2e-16	***
FYEAR1990-91	0.1228	0.11967	1.026	0.304922	
FYEAR1991-92	0.48862	0.1135	4.305	1.73E-05	***
FYEAR1992-93	0.27982	0.12582	2.224	2.62E-02	*
FYEAR1993-94	0.21193	0.11074	1.914	0.055761	.
FYEAR1994-95	0.55568	0.10997	5.053	4.67E-07	***
FYEAR1995-96	0.85013	0.12178	6.981	3.75E-12	***
FYEAR1996-97	0.48343	0.12548	3.853	1.20E-04	***
FYEAR1997-98	0.66219	0.12224	5.417	6.63E-08	***
FYEAR1998-99	0.48287	0.14798	3.263	0.001117	**
FYEAR1999-00	-0.40427	0.11921	-3.391	0.000706	***
FYEAR2000-01	0.15382	0.11529	1.334	0.182261	
FYEAR2001-02	0.19028	0.12225	1.556	0.119726	
QuarterQ2.Jan-Mar	-0.14232	0.07074	-2.012	4.43E-02	*
QuarterQ3.Apr-Jun	-0.06452	0.06706	-0.962	0.336061	
QuarterQ4.Jul-Sep	0.26741	0.06265	4.269	2.04E-05	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.161 on 2492 degrees of freedom
Multiple R-Squared: 0.07651, Adjusted R-squared: 0.07095
F-statistic: 13.76 on 15 and 2492 DF, p-value: < 2.2e-16

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	0.850	0.612	0.731	0.082
90-91	0.961	0.691	0.826	0.082
91-92	1.367	1.016	1.191	0.074
92-93	1.139	0.794	0.967	0.089
93-94	1.029	0.778	0.903	0.070
94-95	1.449	1.099	1.274	0.069
95-96	1.998	1.422	1.710	0.084
96-97	1.394	0.977	1.185	0.088
97-98	1.657	1.177	1.417	0.085
98-99	1.454	0.914	1.184	0.114
99-00	0.567	0.409	0.488	0.081
00-01	0.981	0.723	0.852	0.076
01-02	1.034	0.734	0.884	0.085

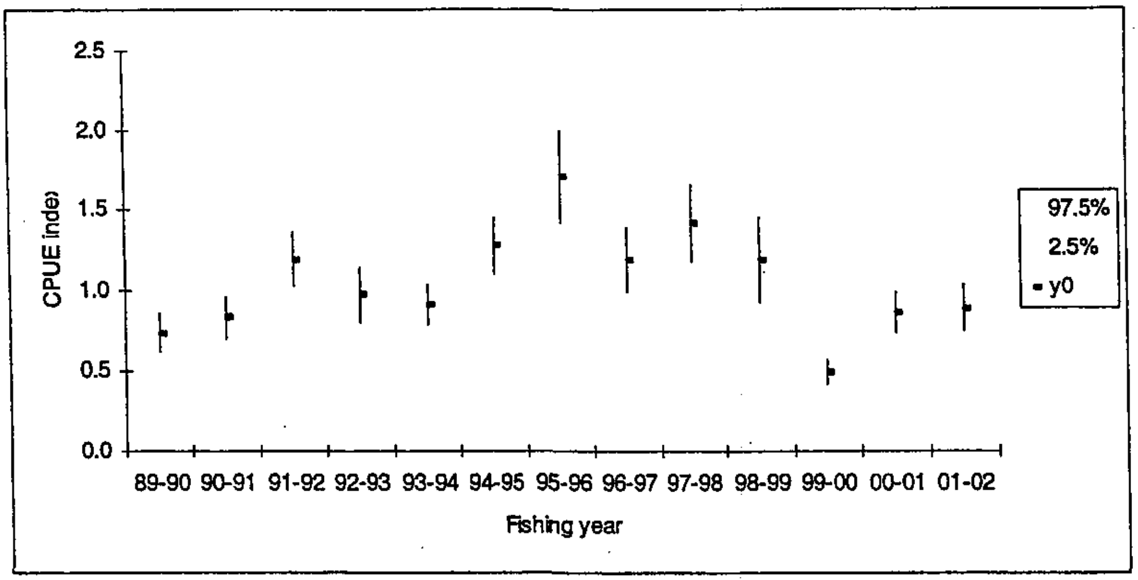

Figure 18: **Canonical CPUE Index for North west coast (mean and 95% confidence intervals).**

Table 8: Standardised analyses tables of Grey Mullet CPUE from the CELR series data for east Northland.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12	118.8	9.9	7.4298	8.51E-14	***
Quarter	3	5.8	1.9	1.4453	2.28E-01	
Residuals	9196	12255	1.3			

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-2.094474	0.046876	-44.681	< 2e-16	***
FYEAR1990-91	0.30672	0.056466	5.432	5.72E-08	***
FYEAR1991-92	0.307954	0.057606	5.346	9.21E-08	***
FYEAR1992-93	0.322878	0.059909	5.389	7.24E-08	***
FYEAR1993-94	0.201406	0.061044	3.299	9.73E-04	***
FYEAR1994-95	0.272598	0.059611	4.573	4.87E-06	***
FYEAR1995-96	0.313973	0.059747	5.255	1.51E-07	***
FYEAR1996-97	0.491009	0.063473	7.736	1.14E-14	***
FYEAR1997-98	0.314605	0.06111	5.148	2.68E-07	***
FYEAR1998-99	0.447813	0.060263	7.431	1.17E-13	***
FYEAR1999-00	0.207215	0.060955	3.399	6.78E-04	***
FYEAR2000-01	0.254655	0.06231	4.087	4.41E-05	***
FYEAR2001-02	0.297195	0.061203	4.856	1.22E-06	***
QuarterQ2.Jan-Mar	0.037866	0.03243	1.168	2.43E-01	
QuarterQ3.Apr-Jun	-0.009884	0.033776	-0.293	7.70E-01	
QuarterQ4.Jul-Sep	0.052521	0.035678	1.472	1.41E-01	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.154 on 9196 degrees of freedom
Multiple R-Squared: 0.01006, Adjusted R-squared: 0.00845
F-statistic: 6.233 on 15 and 9196 DF, p-value: 2.624e-13

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	0.810	0.690	0.750	0.040
90-91	1.096	0.943	1.019	0.037
91-92	1.100	0.942	1.021	0.039
92-93	1.122	0.950	1.036	0.042
93-94	0.996	0.839	0.917	0.043
94-95	1.066	0.904	0.985	0.041
95-96	1.112	0.942	1.027	0.041
96-97	1.338	1.113	1.226	0.046
97-98	1.116	0.939	1.027	0.043
98-99	1.273	1.075	1.174	0.042
99-00	1.002	0.844	0.923	0.043
00-01	1.054	0.882	0.968	0.045
01-02	1.097	0.923	1.010	0.043

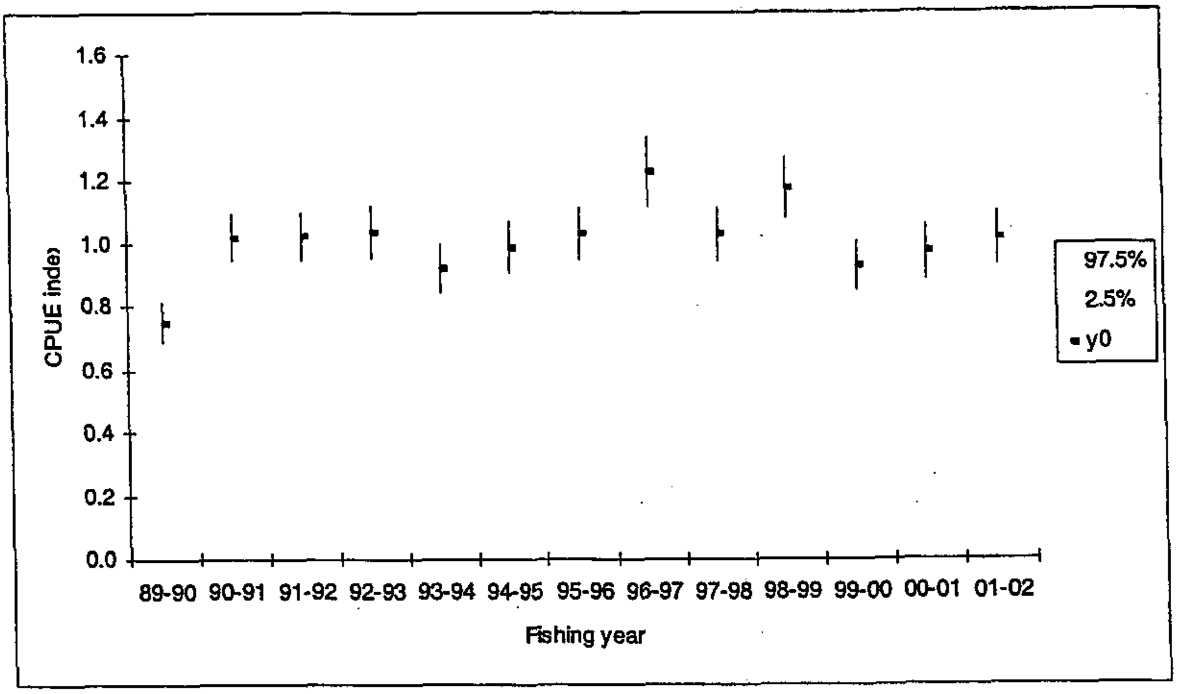

Figure 19: **Canonical CPUE Index for East Northland (mean and 95% confidence intervals).**

Table 9: **Standardised analyses tables of Grey Mullet CPUE from the CELR series data for Hauraki Gulf.**

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
FYEAR	12	293.28	24.44	12.4418	< 2.2e-16	***
Quarter	3	50.82	16.94	8.6231	1.12E-05	***
Residuals	1589	3121.37	1.96			

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.55129	0.10815	-14.344	< 2e-16	***
FYEAR1990-91	-0.02555	0.13003	-0.197	0.844226	
FYEAR1991-92	-0.05757	0.1395	-0.413	0.679904	
FYEAR1992-93	-0.50226	0.16388	-3.065	0.002215	**
FYEAR1993-94	-0.32674	0.18244	-1.791	0.073484	.
FYEAR1994-95	-0.70448	0.18387	-3.831	0.000132	***
FYEAR1995-96	-1.3533	0.15899	-8.512	< 2e-16	***
FYEAR1996-97	-0.96434	0.17644	-5.465	5.35E-08	***
FYEAR1997-98	-0.9412	0.16295	-5.776	9.18E-09	***
FYEAR1998-99	-0.78941	0.19507	-4.047	5.44E-05	***
FYEAR1999-00	-0.98157	0.19259	-5.097	3.87E-07	***
FYEAR2000-01	-0.41705	0.16437	-2.537	1.13E-02	*
FYEAR2001-02	-0.45485	0.13952	-3.26	0.001138	**
QuarterQ2.Jan-Mar	0.03493	0.10428	0.335	7.38E-01	
QuarterQ3.Apr-Jun	-0.18496	0.10023	-1.845	6.52E-02	.
QuarterQ4.Jul-Sep	-0.43656	0.10727	-4.07	4.94E-05	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.402 on 1589 degrees of freedom
Multiple R-Squared: 0.09929, Adjusted R-squared: 0.09079
F-statistic: 11.68 on 15 and 1589 DF, p-value: < 2.2e-16

Canonical Year Indices	97.5%	2.5%	y0	cv
89-90	2.104	1.462	1.783	0.090
90-91	2.071	1.406	1.738	0.096
91-92	2.041	1.325	1.683	0.106
92-93	1.365	0.793	1.079	0.133
93-94	1.677	0.895	1.286	0.152
94-95	1.151	0.612	0.881	0.153
95-96	0.578	0.343	0.461	0.127
96-97	0.878	0.481	0.680	0.146
97-98	0.879	0.513	0.696	0.132
98-99	1.076	0.543	0.810	0.165
99-00	0.885	0.452	0.668	0.162
00-01	1.487	0.863	1.175	0.133
01-02	1.373	0.890	1.131	0.107

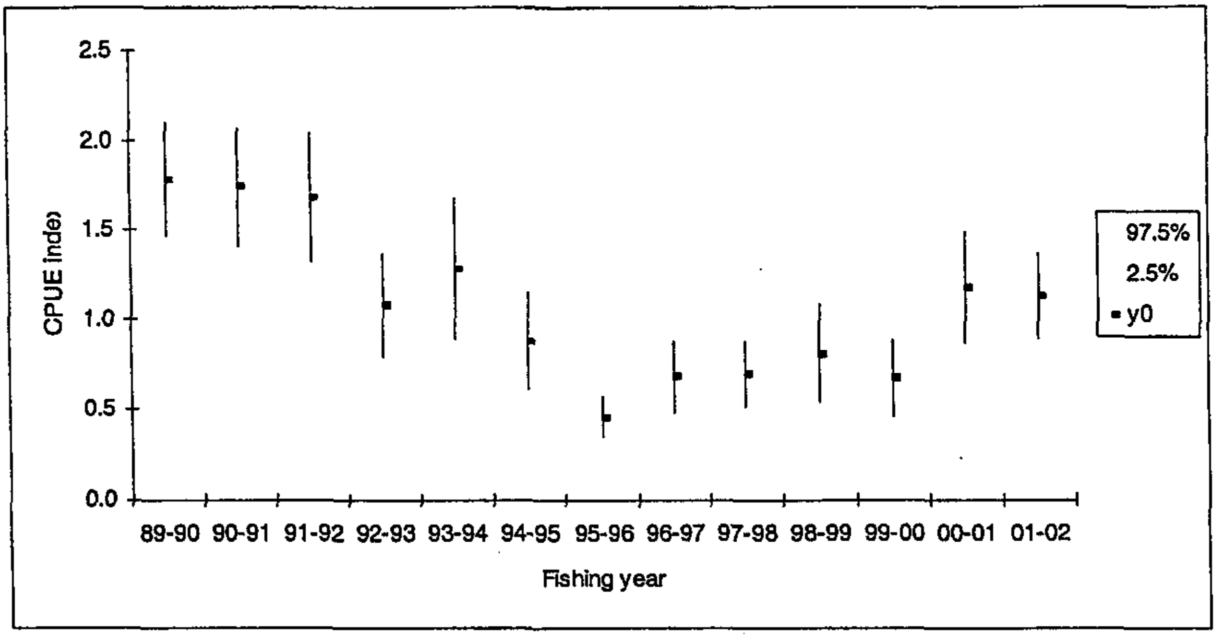

Figure 20: Canonical CPUE Index for Hauraki Gulf (mean and 95% confidence intervals).

APPENDIX B

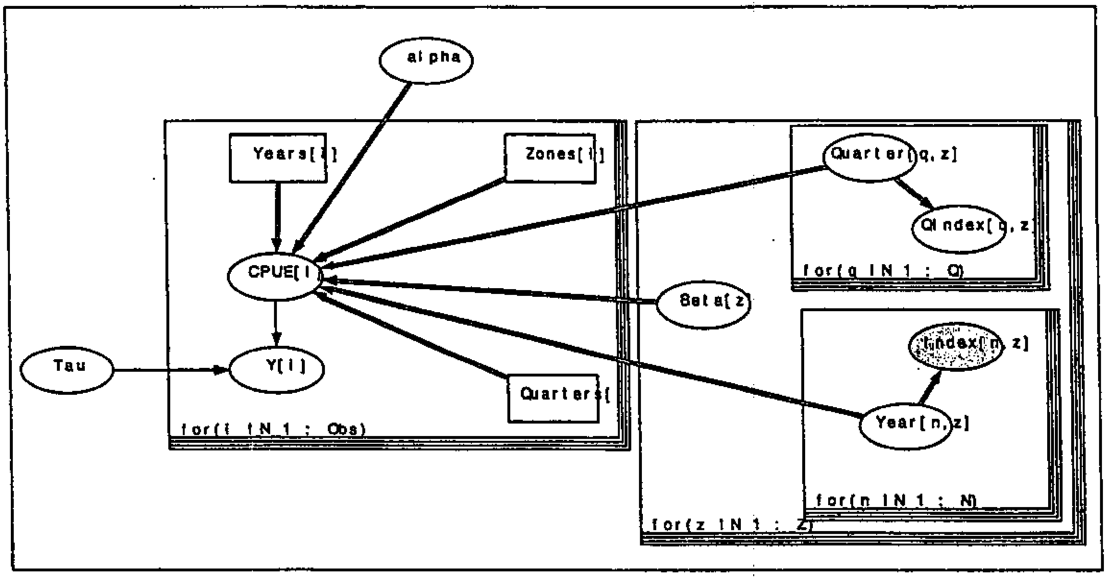

Figure 21: A Directed Acyclic Graph (DAG) representing the Bayesian model.

Table 10: Bayesian model code.

```
model;
{
  for( i in 1 : Obs ) {
    Y[i] ~ dnorm(CPUE[i],Tau)
    log(CPUE[i]) <- alpha + Year[Years[i] , Zones[i]] + Quarter[Quarters[i] , Zones[i]] +
Beta[Zones[i]]
  }
  for( z in 1 : Z ) {
    for( n in 1 : N ) {
      Year[n , z] ~ dnorm( 0.0,1.0E-6)
      Index[n , z] <- exp(Year[n , z] - mean(Year[ , z]))
    }
  }
  Tau ~ dgamma(0.001,0.001)
  for( q in 1 : Q ) {
    for( z in 1 : Z ) {
      Quarter[q , z] ~ dnorm( 0.0,1.0E-6)
      QIndex[q , z] <- exp(Quarter[q , z] - mean(Quarter[ , z]))
    }
  }
  for( z in 1 : Z ) {
    Beta[z] ~ dnorm( 0.0,1.0E-6)
  }
  alpha ~ dnorm( 0.0,1.0E-6)
}
```