THE APPLICATION OF GENERAL LINEAR MODELLING METHODS TO ESTIMATE TRENDS IN ABUNDANCE OF THE HAKE AND ROCK LOBSTER STOCKS OFF SOUTH AFRICA.

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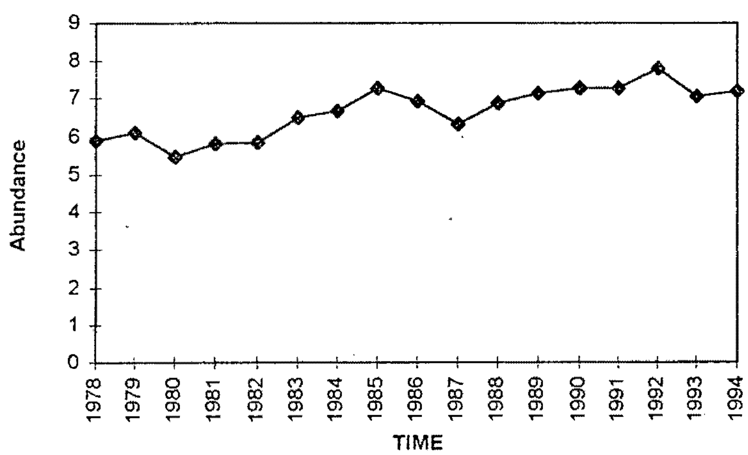

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SECTION B : THE APPLICATION OF GENERAL LINEAR MODELLING FOR DETERMINING TRENDS IN ROCK LOBSTER ABUNDANCE OFF SOUTH AFRICA

ABSTRACT

The two species of Cape hake, *Merluccius capensis* (shallow-water hake) and *M. paradoxus* (deepwater hake), form the mainstay of the bottom trawl industry off South Africa and constitute the country's most valuable fishery. It is therefore important that the status of this resource be assessed regularly to ensure that exploitation is at a sustainable level.

The two Cape hake species are morphologically similar and no distinction is made between them in commercial catch statistics. Consequently, for assessment purposes, the Cape hakes are treated as a single species. It is assumed that two stocks of Cape hake exist, one off the West Coast and another off the South Coast of South Africa. Central to the assessments of these stocks are the catch per unit effort (CPUE) data because it assumed that CPUE is proportional to abundance. The nominal CPUE (hake catch divided by actual time trawled) for both the West and South Coast stocks has shown a steady growth over the period 1978 - 1994, increasing at a rate of 3.8% per annum on the West Coast and 4.2% per annum on the South Coast.

The bulk of this thesis is concerned with determining whether these increases in CPUE are the result of an increasing biomass, or are rather, in part, the result of improved vessel efficiency due to technological advancement or of changes in fishing strategy. The existing CPUE time series had previously been standardised by means of applying power factors which were crudely estimated in the early 1970s and which are likely inappropriate for the current fishing fleets. These CPUE series have therefore been re-standardised by applying the internationally accepted approach of General Linear Modelling (GLM).

Attention is focused on developing a model for the West Coast hake CPUE series. This model is then also applied to the South Coast hake CPUE data. A method is developed and tested by means of simulation to address the fact that the GLM in its simplest form was unable to adjust adequately for targeting on bycatch species. This method is then applied to the actual data. The standardisation of CPUE disaggregated by size category ("small", "medium", and "large") rather than lumping all hake sizes together is also investigated. This is particularly in response to the possibility that extensive illegal use of net liners over the earlier part of the period under

consideration could have biased the CPUE of small hake as an index of abundance, so that the standardised CPUE for the medium and large hake might therefore be more representative of resource abundance trends.

The initial GLM results for the size-aggregated analysis indicated that hake abundance on the West Coast had not increased at the rate suggested by the nominal CPUE, but had actually declined slightly over the period (by 0.4% per annum). There are essentially three factors contributing to this difference between the trends indicated by the nominal and standardised CPUE series:

i) there has been an increase in the average power of vessels as the fleet composition has changed,
ii) fishing has moved to deeper water where nominal CPUE is higher, and
iii) the distribution pattern of the fish has changed with the fish also moving to deeper waters.

A more optimistic view is obtained when correcting for the fact that the initial GLM is unable to adjust adequately for increases in targeting on bycatch species over time (which yields an increase rate of 0.6% per annum), yet this still indicates that the increase in resource abundance is not as substantial as suggested by the nominal CPUE. However, modelling the hake size categories indicates a decrease in small hake abundance of 3.6% per annum, and an increase in the medium plus large hake abundance of 4.0% per annum. These last results are consistent with the hypothesis that the possible extensive use of liners in the earlier years would have biased the CPUE of small hake, so that the standardised CPUE of medium and large hake might be a more representative index of resource abundance over the whole period considered (1978 - 1994), although there remain some concerns about the comparability over time of the manner in which the split between size categories has been recorded.

The results obtained from the South Coast analyses indicate a 3.6% increase in abundance per annum for all hake sizes combined, and 1.4% and 5.0% increases for the small and medium plus large size categories respectively. Since the minimum mesh size is set at 75mm for the South

Coast one would expect that liners were not used as extensively on this coast, and this is reflected in the lesser difference in trends for these two size categories than is the case for the West Coast.

The West and South Coast rock lobster fisheries are two further important South African fisheries, the former being the country's third most valuable. CPUE information for both of these fisheries are fundamental inputs for assessment purposes, and the models applied to standardise the CPUE for each fishery are developed and discussed. The most recent standardised CPUE series for the West Coast indicates a 4.2% increase in abundance per annum (for the period 1993/94 - 1996/97), whereas that for the South Coast indicates a 1.6% decrease per annum (for the period 1977/78 - 1995/96) in abundance.

OVERVIEW OF THESIS

This thesis comprises two sections. Section A deals with the application of General Linear Modelling (GLM)[1] for determining trends in abundance of the hake resource off South Africa from catch per unit effort (CPUE) data, whereas Section B reports similar evaluations of resource abundance trends for the two major South African rock lobster populations.

Outline of Section A

Chapter 1 explains the need for standardising the hake (*Merluccius capensis* and *M. paradoxus*) CPUE data. Chapters 2 and 3 discuss the history of the South African hake fishery and the biology of the Cape hakes respectively.

Chapter 4 provides background information on the importance of standardising effort, and the allocation of power factors for the South African demersal fleet is discussed.

Chapter 5 describes the database from which the data for the CPUE analyses were obtained. The manner in which the data were refined to prepare them for analysis purposes is discussed, as are the limitations of some of the information in the database in the context of GLM analyses.

Chapter 6 reports various trends evident in the data for the West Coast, and Chapter 7 provides a detailed account of the basic GLM analyses applied to the West Coast hake CPUE time series.

Chapter 8 explains why the basic GLM is unable to adjust for changes in targeting (hake vs "bycatch" species) adequately. A method to correct for this inadequate adjustment is proposed and tested by means of simulation, and is then applied to the actual data.

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[1]Statisticians frequently distinguish between "General Linear Models" and "Generalized Linear Models" on the basis that the former are restricted to normally distributed errors whereas the latter encompass a wider range of error distributions. Sometimes the abbreviation GLM is reserved for the latter. However, this thesis follows general practice in fisheries of referring to both approaches by the abbreviation GLM. In fact, for reasons detailed in Chapter 1, only models with (assumed) normally distributed errors are evaluated herein.

Chapter 9 revisits the refinements made to the database in readying it for analysis purposes, and Chapter 10 discusses the model applied to the revised data to attempt to correct for the original inadequate bycatch targeting adjustment.

Chapter 11 describes the standardisation of the hake CPUE data disaggregated by size category. This is in response to a suggestion made that the extensive illegal use of net liners over the early part of the period under consideration would have biased the CPUE of small hake, and hence also a composite CPUE measure for all size classes combined, as indices of hake abundance.

Chapter 12 details the GLM analyses conducted for the South Coast hake CPUE by applying the same methodology with a slightly amended model to that used for the West Coast analyses.

Chapter 13 provides a general discussion and conclusions with respect to abundance trends in the hake resource, with suggested future work being outlined in Chapter 14.

Outline of Section B

Chapter 15 briefly introduces the methods used to assess the status of the West and South Coast rock lobster resources, highlighting the fact that CPUE data provide inputs of fundamental importance for the assessments of both resources.

Chapter 16 is concerned with the South Coast rock lobster (*Palinurus gilchristi*) resource. The history of the fishery is described as is the biology of the species. The information contained in the South Coast rock lobster database is detailed, and the GLM analyses applied to the CPUE data over a three year period are discussed. Special features of the fishing operations are highlighted, and manners of taking them into account in a GLM context are discussed.

Chapter 17 is concerned with the West Coast rock lobster (*Jasus lalandii*) resource. The history of the fishery is detailed, as is the biology of the species. The various West Coast rock lobster databases are described and the GLM analyses applied to the CPUE data over a two year period are discussed.

Conclusions arising from the work carried out to standardise the West and South Coast rock lobster CPUE data are listed in Chapter 18, as are suggestions for further work.

Notes

In each case considered the modelling has been carried out by using the SAS (1985) GLM procedure (since this procedure can take account of an unequal number of observations for the different combinations of categorical variables specified in the model).

For GLMs it is generally the ANOVA table, the parameter estimates and their associated standard errors that are normally reported. In this thesis, however, attention is focused rather on a statistic of key import and interest for the purposes of management advice, i.e. the trend of abundance indicated by the standardised CPUE index, which is reflected by the slope statistic (defined in the glossary - page 12), and sensitivity of estimates thereof to alternative model specifications. For completeness however, the output from the final West Coast hake model adopted is shown in the Output Appendix. This Appendix also includes the SAS program used to generate the output.

GLOSSARY

The global definitions for certain terms that are used throughout this thesis are as follows:

r^2	the proportion of variation in the dependent variable that can be accounted for (explained) by the model being applied.
slope	the average percentage change in resource abundance per annum (obtained from a regression of *ln*(standardised CPUE) against time).
significant	implies statistical significance at the 5% level.
n	the number of observations fitted in the various GLMs.
p	the number of parameters estimated by the model.

SECTION A : THE APPLICATION OF GENERAL LINEAR MODELLING FOR DETERMINING TRENDS IN HAKE ABUNDANCE OFF SOUTH AFRICA

CHAPTER 1 - INTRODUCTION

Heavy exploitation of the Cape hakes (*Merluccius capensis* and *M. paradoxus*) off South Africa by both the local and a growing international fleet in the 1960s led to mounting concern that the resource was being depleted rapidly. Concerted efforts were made to collect and analyse catch and effort data from the fishery, and in the mid-70s the first scientific assessments of the Cape hakes were undertaken. Central to these past and the current assessments are the catch per unit effort (CPUE) data, because it is assumed in these assessments that CPUE is proportional to abundance (or, in spatially stratified analyses, that CPUE is proportional to density which is then multiplied by the stratum area to provide an index of abundance).

Over time technologies have changed, vessels have been upgraded and fishing patterns have shifted both spatially, with time of year, and in the extent to which species other than hake were targeted. Each of these factors could potentially have an impact on CPUE, biasing it as an indicator of trends in abundance. The effects which could bias CPUE in this way therefore need to be factored out in an exercise which is customarily called "standardisation", and this is usually achieved by applying the technique of General Linear Modelling (GLM), as is customary in fisheries assessments internationally (the development of the use of GLM for this purpose in fisheries is discussed in Section 4.2). It is important that commercial CPUE data be standardised because they are not collected on the basis of some balanced design, as are trawl data in scientific surveys, which thus provide unbiased estimates directly without the need for such standardisation.

The historic CPUE time series used previously for assessment purposes had been standardised by applying power factors that were calculated crudely in the early 1970s (see Section 4.3), and that most probably are no longer appropriate. Furthermore, this method of standardisation fails to account for technological improvements and shifts in fishing patterns. The need to re- standardise the hake CPUE time series was first identified in the early 1980s, but the data were stored on various media (punch cards and magnetic tapes), and not in the same format, which made the extraction of these data difficult given the limited computer facilities at the time. Punt (1992) made a first attempt at standardising a subset of the CPUE data by means of applying a linear model, but concluded that the resulting year factors were poorly determined, and that a much larger data series was required to obtain reliable results. In 1994 hake CPUE data covering the period 1978 - 1994 were extracted from the various storage sources and made available in encoded format so that GLM-based standardisation of these data could be carried out.

It is assumed in these GLM analyses that the CPUE data are log-normally distributed. Butterworth (1996a) defends this assumption by arguing that it allows for the use of statistical packages which assume normally distributed errors; this is both in the interest of keeping analyses simple and because the overall error structure is in any case the consequence of a number of processes which no single "pure" error model is likely to capture completely. More recently other error structure models have, however, been applied, e.g. at the International Council for the Conservation of Atlantic Tunas (ICCAT), and have been found to be more appropriate than the traditional assumption of log-normality that was made initially. These include Poisson, gamma, negative binomial and delta-lognormal models (e.g. Brown, 1994; Cooke and Lankester, 1995) and it appears that the most appropriate error model depends on the dataset being analysed.

One problem encountered with assuming log-normality is the occurrence of zero CPUE values, and these are usually dealt with by adding a small constant (see Section 7.4) to the CPUE before taking logarithms. Some of the alternative methods however, e.g. the delta-lognormal and Poisson do provide for a finite probability of zero catch (Cooke and Lankester, 1995), and may therefore be worthwhile investigating in the South African context in due course. Note that for the delta-lognormal method, the probability of non-zero catch is modelled separately from that of zero catch (for which a different distributional assumption, e.g. binomial, may be made), even though it remains assumed that the non-zero catches are log-normally distributed (Cooke and Lankester, 1995).

However, at the time this work commenced, packages available to the author could not implement models based on distribution assumptions other than normal for the large numbers of explanatory variables used in these studies. This work had therefore to be restricted to models based upon the assumption of distribution normality.

Since 1990 estimates of management quantities obtained from an Operational Management

Procedure (OMP) have been used to set total allowable catches (TACs) for the South African hake resource. An OMP comprises a set of rules which specify the data to be collected, the methods employed to collect these data and the management action to be taken based on results obtained from analysing the data (Butterworth *et al.*, 1997). The ability of an OMP to satisfy management objectives given uncertainties that exist about resource status and dynamics is of vital importance and this is tested by means of simulation (Punt and Smith, 1997). Industry participation in the development of OMPs is encouraged so that they can suggest scenarios to which candidate OMPs should be robust (Punt and Smith, 1997). In South Africa, an OMP is generally left to operate automatically for a period of 3 to 5 years, after which a re-evaluation is initiated if necessary (De Oliveira *et al.*, in press).

The OMP used for the Cape hakes has been based on an $f_{0.2}$ harvesting strategy coupled with an age-aggregated dynamic production model using the Schaefer form of the surplus production function. It utilises commercial CPUE data and survey biomass indices, and was selected on the basis that it appeared to offer the best trade-off between risk of the resource being reduced to undesirably low levels and reward to the Industry in terms of maintaining high levels of catch (Punt *et al.*, 1995). This management procedure encompasses a feedback control in that as new data become available annually, the values of the population dynamics parameters used to compute the TAC are updated (De Oliveira *et al.*, in press).

By the mid-1990s, however, the appropriateness of this hake management procedure was being questioned on numerous counts. It appeared that :

1) the Schaefer form of the production model was no longer the most appropriate model to apply since it did not fit the CPUE data satisfactorily in the more recent years (Geromont and Butterworth, 1997a) (this was later attributed to the fact that an age-aggregated model was not able to take account of a change in fishing selectivity away from smaller fish (Geromont and Butterworth, 1998));

2) the commercial CPUE data were potentially positively biased as a result of applying outdated power factors to standardise these data (Anon, 1997a); and

3) treating the CPUE series as a single homogenous series was possibly invalid (Anon, 1997a); a split series of pre-and post-1977 CPUE data was considered more appropriate given that prior to 1977 the fishery was dominated by foreigners, whereas after 1977 the fishery became almost exclusively South African as a result of a 200nm exclusive economic zone (EEZ) being declared in 1977 (Geromont and Butterworth, 1996).

Additionally, there was growing concern about the different trends being shown by the commercial CPUE series and the survey biomass indices (Figure 1), although strictly these trends were not significantly different, primarily as a consequence of the large inter-annual variation in the survey indices.

The re-evaluation of the OMP and the re-standardisation of the CPUE data have thus been carried out in parallel, with progress of the OMP depending on the progress of the GLM analyses. The focus and pace of the GLM analyses has been driven largely by interactions between members of the demersal working group (DWG) of the South African Sea Fisheries Research Institute (SFRI) and Industry at INSEF (Industry and Sea Fisheries Forum) meetings. INSEFs are informal information sessions which are usually initiated by Industry at times when they either wish to impart or obtain information relevant to a specific fishing industry (in this case the demersal fishing industry, which focuses particularly on hake). In recent years private scientific consultants (OLRAC cc) have been contracted by the Industry to carry out analyses independent of those being carried out in-house at SFRI, and much time has been spent at INSEF meetings on attempting to reach agreement between SFRI and OLRAC on various issues related to the GLM analyses. The entire process has therefore been extremely dynamic, with new data, perceptions and information continually being taken into account.

A target date of mid-1997 was originally set for the revised OMP to be in place so that it could be implemented to provide a recommendation for the hake TAC for 1998 (however, this target was eventually postponed by one year). This required that the GLM analyses be completed timeously so that the re-standardised CPUE could be used both in the development of the revised OMP, and subsequently when it was implemented. The work reported here therefore chronicles what has been done (primarily by the author) over a period of approximately two years in an attempt to re-standardise the hake CPUE for these purposes, and is a consolidation of the list of unpublished documents that is given in the Section entitled “Unpublished working group documents authored/co-authored by the writer of this thesis”.

CHAPTER 2 - THE HISTORY OF THE SOUTH AFRICAN HAKE FISHERY

The South African demersal (bottom trawl) fishery commenced at the turn of the 20th century (Payne and Punt, 1995). Hake were initially not a very important component of the South African fishery (Lees, 1969), but food shortages experienced after World War I led to an increasing interest in fish, particularly hake, an abundant resource that had just been discovered off Cape Town (Payne and Punt, 1995).

2.1 Stock identification and separation

Most of the fish species caught off southern Africa fell under the auspices of the International Commission for the South East Atlantic Fisheries (ICSEAF), a body that was formed in 1972 in response to the increasing concern about over-exploitation of the hake stocks in the region. The area under the jurisdiction of ICSEAF was divided into a number of Divisions (Figure 2), some of which were combined for the purposes of assessing the various stocks that had been identified. The Cape hakes are distributed along the entire coastline, from Division 1.3 through to Division 2.2 (De Villiers, 1985), and for the purposes of this thesis, only those that occur in Divisions 1.6 and 2.1 and 2.2 are considered since it is in these Divisions that the South African demersal fleet fishes. Divisions 2.1 and 2.2 are lumped together because catches in Division 2.2 are fairly small, and the distribution of the catches do not extend very far into this Division (Andrew, 1986).

Although the boundary between ICSEAF Divisions 1.5 and 1.6 is the 30°S line, a political boundary separating South Africa and Namibia exists (shown by line (a) in Figure 2). Since catches are declared by country, it is the political and not the ICSEAF boundary that is used when declaring catches. It is therefore evident that some of the catches made in ICSEAF Division 1.5 will be allocated to Division 1.6, and some catches in Division 1.6 will be allocated to Division 1.5. R. Leslie (SFRI, pers. comm.) suggests that line (b), re-dividing Divisions 1.6 and 2.1, and more or less parallel to the political boundary line (a), was introduced to compensate for the allocation of catches at the South Africa/Namibian political border. Catches continue to be declared by ICSEAF Division, but the diagonal lines (a) and (b) instead of the conventional ICSEAF boundaries are used to define the Division from which catches were taken.

It is assumed for management purposes that two stocks of Cape hake exist: one off the West and another off the South Coast of South Africa (Punt *et al.*, 1995), the boundary between the two stocks being identified by line (b). The status of each stock is assessed separately, and the assessments generally lead to a decision for a TAC allocation split of approximately 2:1 between the West and South Coasts respectively (Punt *et al.*, 1995). Since boundary line (b) was arbitrarily assigned, and was not based on any biological consideration, R. Leslie (SFRI, pers. comm.) suggests that the positioning of this line rather be made on biological grounds which would truly separate the West and South stocks, and suggests that such a boundary may be in the region of the 20°E line (at which there is some break in the distribution), i.e. the formal ICSEAF boundary between Divisions 1.6 and 2.1.

2.2 Catch History

Annual catches, effort and CPUE for the West Coast hake fishery are shown in Table 1. The catch data which cover the period 1917 - 1954 were estimated by Andrew (1986) from historical records published by Chalmers (1976). These catches have been increased by 39% to account for discarding, in accordance with a decision published by ICSEAF (1978). Post-1954 data include catch, effort and CPUE. The catch, effort and CPUE series for the South Coast hake fishery are shown in Table 2.

TABLE 1 : Total catch, effort and CPUE for the Cape hakes on the West Coast of South Africa (source : Andrew, 1986; Leslie, 1997a).

Year	Catch (tons)
1917	1 000
1918	1 100
1919	1 900
1920	-
1921	1 300
1922	1 000
1923	2 500
1924	1 500
1925	1 900
1926	1 400
1927	800
1928	2 600
1929	3 800
1930	4 400
1931	2 800
1932	14 300
1933	11 100
1934	13 800
1935	15 000
1936	17 700
1937	20 200
1938	21 100
1939	20 000
1940	28 600
1941	30 600
1942	34 500
1943	37 900

Year	Catch (tons)	Effort (days)	CPUE (tons/day)
1944	34 100		
1945	29 200		
1946	40 400		
1947	41 400		
1948	58 800		
1949	57 400		
1950	72 000		
1951	89 500		
1952	88 800		
1953	93 500		
1954	105 400		
1955	115 400	6 667	17.31
1956	118 200	7 558	15.64
1957	126 400	7 675	16.47
1958	130 700	8 038	16.26
1959	146 000	8 979	16.26
1960	159 900	9 237	17.31
1961	148 700	12 299	12.09
1962	147 600	10 409	14.18
1963	169500	12 133	13.97
1964	162 300	11 116	14.60
1965	203 000	18 727	10.84
1966	195 000	18 344	10.63
1967	176 700	17 652	10.01
1968	143 600	14 346	10.01
1969	165 100	19 153	8.62
1970	142 500	19 710	7.23

Year	Catch (tons)	Effort (days)	CPUE (tons/day)
1971	202 000	28 491	7.09
1972	243 933	49 782	4.90
1973	157 782	31 747	4.97
1974	123 000	26 452	4.65
1975	89 617	19 231	4.66
1976	143 894	26 896	5.35
1977	102 328	21 142	4.84
1978	101 140	17 142	5.90
1979	92 704	15 123	6.13
1980	101 538	18 529	5.48
1981	100 678	17 328	5.81
1982	85 970	14 646	5.87
1983	73 677	11 352	6.49
1984	88 410	13 255	6.67
1985	99 590	13 661	7.29
1986	109 091	15 742	6.93
1987	104 010	16 380	6.35
1988	90 131	13 100	6.88
1989	84 896	11 857	7.16
1990	78 918	10 826	7.29
1991	85 521	11 780	7.26
1992	86 280	11 090	7.78
1993	98 110	13 897	7.06
1994	101 230	14 047	7.19
1995	93 800	14 520	6.65
1996	91 520	12 534	7.34

TABLE 2 : Total catch, effort and CPUE for the Cape hakes on the South Coast of South Africa (source : Newman, 1977 ; Leslie, 1997a).

Year	Catch (tons)	Effort (hours)	CPUE (tons/hour)
1964	5 000		
1965	3 000		
1966	20 000		
1967	17 340		
1968	31 370		
1969	41 700	32 578	1.28
1970	27 800	22 787	1.22
1971	34 500	30 263	1.14
1972	51 388	80 294	0.64
1973	77 356	138 136	0.56
1974	100 909	186 869	0.54
1975	73 835	199 554	0.37
1976	57 670	144 175	0.40
1977	40 472	96 362	0.42
1978	38 889	64 851	0.41
1979	53 831	117 024	0.46
1980	47 571	108 116	0.44
1981	35 138	87 845	0.40
1982	46 826	91 816	0.51
1983	41 174	85 779	0.48
1984	43 196	78 538	0.55
1985	56 223	83 915	0.67
1986	51 167	81 217	0.63
1987	41 826	76 047	0.55
1988	44 969	83 276	0.54
1989	51 772	101 514	0.51
1990	58 256	97 093	0.60

TABLE 2 continued.

Year	Catch (tons)	Effort (hours)	CPUE (tons/hour)
1991	55 479	89 482	0.62
1992	55 320	75 781	0.73
1993	43 363	58 599	0.74
1994	45 590	62 452	0.73
1995	45 810	70 477	0.65
1996	68 800	80 952	0.84

Note that historically the CPUE for the two coasts have been recorded in different units of effort. The reason for this difference stems from the differing topography of the fishing grounds on the two coasts. The West Coast consists of large areas of trawlable ground and very little search time is therefore required between trawls; hence the average time spent fishing per day remains fairly constant. Tons/standard day were therefore regarded as an appropriate measure of CPUE. The South Coast, in contrast, consists of small patches of trawlable ground, and much time is spent moving from one trawlable ground to another. In this case tons/standard hour is considered a more reliable index. Note that the "standard" days/hours referenced here incorporates a crude allowance for vessel power factor adjustment, as explained in Section 4.3.

Table 1 indicates that in the first few years of the hake fishery catches off the West Coast averaged little more than 1000t. By the 1960s annual hake catches had well exceeded 100 000t and international interest in this blossoming fishery was sparked. Consequently, fleets from countries such as Poland, the Soviet Union, Spain and Germany (Payne, 1989) joined the local fleet during the 1960s in a quest for a share in this vast resource.

To illustrate the impact on catches as a result of the advent of foreign vessels, Table 3 (reproduced from Botha, 1970) gives a breakdown of the hake catches taken by the local and foreign fleets off South Africa and Namibia (S.W.A.) over the period 1960 - 1968. From this Table it is evident that the total hake catch increased considerably over this period, but that the catches made by the South African fleet as a proportion of the total catch declined from 99% in 1960 to a mere 26% in 1967.

TABLE 3 : Catches of hake landed from the South-east Atlantic, 1960 - 1968. (Thousands of tons, live weight.) (Source : Botha, 1970.)

Countries	1960	1961	1962	1963	1964	1965	1966	1967	1968
Angola	0.4	0.2	0.2	0.2	0.1	-	0.1	0.2	
Germany (East)							1.2		
Germany (Fed. Rep. of)						0.4	7.3	13.1	
Israel		0.3	0.3	0.9	1.0	1.0	7.0		
Japan						17.4	31.8	40.0*	
South Africa	115.0	106.9	105.8	102.3	106.5	100.6	121.7	118.5	118.2
S.W.A	+**	+**	+**	+**	+**	+**	+**	0.8	
Spain				18.0	46.3	118.3	156.1	184.6	
U.S.S.R	0.5	0.5	0.5	-	2.2	81.8	135.4	104.4	
Total	115.9	107.9	110.9	121.4	156.1	319.5	460.6	461.6*	

* Provisional figure at the time of Botha's computation.

** Undefined in Botha (1970).

In 1972 a peak international hake catch of 1 115 000 tons was made in South African and Namibian waters combined, the contribution of hake caught off South Africa being just below 300 000t (Payne and Punt, 1995). At that stage over 300 large vessels were fishing for hake (Botha, 1985). The resource was not able to support the increasing fishing pressure and catch rates declined rapidly (Payne and Punt, 1995).

ICSEAF was established in 1972 as a result of mounting concern over the depletion of the hake stocks due to this increased exploitation. Priority was given to stock assessment in the various Divisions identified, and steps were taken to reduce the amount of effort directed at hake (Andrew, 1986).

One such step resulted from a study by Ikeda (1974) which recommended that the mesh size used for catching hake be increased to 110mm. This would allow for the escape of juveniles (Payne, 1989), and although it was expected to result in initial declines in catches in the short term (Ikeda, 1974), the long-term benefits were argued to outweigh these costs. It was predicted that the long-term benefits would be in the form of increased catches of potentially between 5 and 13% depending on the current mesh size being used (Newman, 1977), whereas the estimated immediate losses in the first year would be in the region of between 5 and 20% (Ikeda, 1974).

A mesh size of 102mm had been imposed on the local fleet from 1933, and in 1975 a minimum mesh size of 110mm was adopted and applied to the entire international hake fishery. The process of converting to a 110mm mesh size was phased in over a year, and it was directed at those vessels that caught more than 30% by mass of hake in each haul. If the percentage was less i.e. the vessel was engaged in mixed-species fishing, then the minimum mesh size allowed was the one authorized under the national regulations of the flag country at the time that the 110mm mesh size was adopted for hake (Newman, 1977). To enforce the mesh size regulation, ICSEAF initiated an international inspection scheme and later allocated quotas to participating countries (Payne, 1989).

The minimum mesh size, inspection scheme and quota allocation helped conserve the stock to some degree, but Payne and Punt (1995) state that it became clear to local authorities that the foreign fleets had little interest in preserving the hake stocks off southern Africa. Therefore, on 1 November 1977 a 200 mile exclusive fishing zone was declared for South African waters (Payne, 1989). This resulted in the majority of foreign vessels being removed from South African waters. Some of these vessels continued to fish off Namibia where, because of political uncertainty, a 200 mile exclusive zone had not yet been enforced (Andrew, 1986).

2.3 The current fishery

The hake fishery has since 1983 been restricted to a local fishery and catches are controlled by TACs which are set annually. The numbers of vessels operating in the fishery are limited and certain areas are closed to trawl fishing (Anon, 1997b). In the early 1990s the offshore fleet consisted of 63 trawlers, 37 of which were large factory/freezer vessels and the balance ice-carrying vessels, whereas the inshore fleet consisted of 35 small trawlers (Payne and Punt, 1995).

Quotas are allocated to fishing companies from the TAC; two large companies are allocated approximately 80% of the TAC in equal amounts, while a few smaller companies and quota holders are allocated quota from the remainder (Payne and Punt, 1995).

The minimum mesh size of 110mm that was imposed in 1975 is still enforced on the West Coast, while on the South Coast a minimum mesh size of 75mm was introduced in 1991 to accommodate the mixed-species nature of the fishery. Fishing is prohibited within 5 miles of the coast on the West Coast, and only vessels belonging to the inshore fishery are allowed to fish in waters shallower than 110m on the South Coast.

Levies are paid to the state on each kilogram of hake that is landed and the monies contribute towards research within South Africa (Payne and Punt, 1995). Anon (1997b) gives a breakdown of the relative importance of hake catches, both in terms of total commercial catches and in terms of monetary value. The nominal hake catches (tons round mass) as a percentage of total trawl catches in South Africa for 1985, 1990 and 1995 were 75%, 56% and 77% respectively. Of all South African commercial catches, these percentages were respectively 23%, 25% and 24%. These figures indicate that hake catches continue to dominate the trawl fishery, and also contribute considerably to the total commercial catches of the country. In fact, anchovy catches were the only catches higher than that of hake for the periods quoted, and catches of anchovy fluctuate widely from year to year, so that in some years hake catches have been higher than those of anchovy. The amount of revenue (wholesale value) generated by the demersal fishery as a percentage of the total revenue generated by all commercial fishing sectors in 1993, 1994 and 1995 was 52%, 48% and 46% respectively. These figures illustrate the importance of the demersal fishery, of which hake makes up a substantial proportion, in contributing to the country's welfare.

CHAPTER 3 - THE BIOLOGY OF THE CAPE HAKES

3.1 Distribution

The Cape hakes are found in the region of Bahia de Farto (12°S off Angola), around the southern African coast to Port Elizabeth (33°S) (Botha, 1985). It was only in the early 1960s that scientists discovered that two species of hake existed off the coast of South Africa (Payne and Punt, 1995), and that the distribution of these two species was depth dependent (van Eck, 1969; Botha, 1973). *M. capensis* were found to inhabit shallow waters, whereas *M. paradoxus* inhabit deep waters with some intermingling of species at intermediate depths (van Eck, 1969; Botha, 1973). It was also discovered that for both species, small fish occur at shallower depths than large fish (Botha 1985), i.e. there is a size gradation with depth. Payne and Punt (1995) report that shallow-water hake are found from close inshore to about 400m depth, whereas deep-water hake are not found shallower than 150m, and occur to maximum depths of approximately 900m.

Both species of Cape hakes are caught on the West Coast of South Africa (Andrew, 1986), the most dominant species being *M. paradoxus*, which at times has contributed as much as 90% to total landings (Payne, 1989). *M. capensis* dominates catches off the South Coast on the Agulhas Bank, contributing approximately 70% to catches (Payne, 1989). Payne (1989) suggests that the differing relative abundances of the two species could be linked to the width of the continental shelf and the steepness of the adjacent continental slope, and possibly also to sea temperature. He comments that shallow-water hake are more abundant where the shelf is widest and the slope steepest (i.e. on the Agulhas Bank, off Walvis Bay and off the Orange River mouth), whereas deep-water hake are more abundant where the shelf is narrow and the slope less steep (off the south-western Cape of South Africa and south-west of Luderitz).

3.2 Species identification

It is not easy to distinguish between the two species of Cape hakes in commercial landings and because they are not separated out on landing, they have to date been treated as a single species for stock assessment purposes (R. Leslie, SFRI, pers. comm.). There are, however, morphological differences. Van Eck (1969) reports that *M. capensis* has tubercules of a uniform white colour, whereas *M. paradoxus* has a small black area approximately at the centre. Furthermore, he observed that *M. capensis* and *M. paradoxus* have 49 - 51 and 54 - 57 vertebrae respectively. Kolender (1975) reports that the otoliths of *M. capensis* are wedge shaped, whereas those of *M. paradoxus* are bean-shaped. Other subtle differences between the two species are that *M. paradoxus* are longer and thinner than *M. capensis*, they have proportionally larger eyes, and the dorsal parts are blacker in *M. paradoxus* and more coppery in *M. capensis* (Andrew, 1986).

3.3 Spawning and migration

Hake spawning takes place twice a year, a major peak occurring in November/December for both species, and a secondary peak in February/March sustained mainly by *M. paradoxus* (Botha, 1986). *M. paradoxus* spawn at an earlier age than *M. capensis*, and males spawn at a younger age than females for both species (Payne and Punt, 1995). It is believed that multiple spawning of females is unlikely, although the possibility of two spawnings a year is not ruled out (Payne, 1989). On the other hand, males may be capable of multiple spawning given that they grow at a slower rate than females after maturing (Payne and Punt, 1995), but this has not been proved.

Catch rates of hake during the day are greater than at night, although at certain times of the year the day-time peak is considerably flattened (Botha, 1973). This effect is evident in Figure 3. The flattened day-time peak appears to correspond with the main spawning season of Cape hakes (Payne, 1989) and because spawners are not caught in trawls, it has been inferred that spawning takes place somewhere in mid-water. From this Botha (1973) concluded that vertical migration takes place but he suggests that no extensive horizontal migration takes place because there are no noticeable seasonal shifts with depth in fishing operations.

M. capensis and *M. paradoxus* spawn at different water depths, thus enabling them to maintain their specific integrity (Botha, 1973). Payne (1989) reports that hake have responded to heavy exploitation over the past two decades by maturing at a younger size and age, and suggests that this is a density dependent response to attempt to maintain their output of spawning products given the reduced abundance of older fish.

3.4 Growth

Botha (1971, 1986) reports that females of both species have similar growth rates, whereas the growth rates of males differ. *M. paradoxus* males were found to grow at a slower rate than *M. capensis* males (Botha, 1971), possibly as a result of *M. paradoxus* males expending greater energy over a longer spawning period (Botha, 1971). Botha (1986) reports that the females of both species matured at a greater length and age than the males, 50% maturity being achieved at 470 - 480mm by females and 360 - 380mm by males (~ 4.8 and 3.8 years of age respectively). Females dominate the sex ratios in the catches by 1.5:1 and 1.7:1 for *M. capensis* and *M. paradoxus* respectively, and sex ratios are more disparate for mature, large fish (Botha, 1986). Very few males older than age 8 for *M. capensis* and age 6 for *M. paradoxus* are found in commercial catches (Botha, 1971 ; Payne, 1989).

3.5 Feeding

Numerous studies (Payne, 1989 ; Payne and Punt, 1995 ; Pillar and Barange, 1993 ; Punt *et al.*, 1992) report on the feeding habits of the Cape hakes. From these it is evident that hake are opportunistic feeders, the seasonal and regional differences in their diet reflecting local variations in food availability. Juveniles feed mainly on crustaceans, switching to a fish diet as they become bigger. Both species are cannibalistic, the old fish of each species feeding on young fish of the same species. Adult *M. capensis* also feed on juvenile *M. paradoxus* since they co-occur at intermediate depths, but adult *M. paradoxus* do not feed on juvenile *M. capensis* because of spatial separation (juvenile *M. capensis* occurring in shallow water, and adult *M. paradoxus* occurring in deep water). A study by Punt and Leslie (1995) indicated that the stomach contents (by mass) of *M. capensis* aged 6+ constituted on average 23% *M. paradoxus* and 11% *M. capensis*, while that of *M. paradoxus* aged 6+ contained on average 32% *M. paradoxus*.

CHAPTER 4 : BACKGROUND TO STANDARDISING CPUE

4.1 General

Nominal CPUE is defined by the ratio of total catch to total effort (expressed in terms of some unit of time spent fishing) and it is assumed that it is directly proportional to stock density and can therefore serve as an index of abundance when integrated over area. The relationship between CPUE and abundance can be derived from the catch equation, which relates catch, fishing effort and average fish density, i.e.

$$C = qED \qquad \textbf{(1)}$$

where C is the catch, q is a catchability coefficient (related to the efficiency of a vessel), E is the effort and D is the average stock density (e.g. Campbell *et al.*, 1995). Re-arranging the catch equation the following relationship between nominal CPUE and density is derived:

$$C/E = qD \qquad \textbf{(2)}$$

indicating that changes in nominal CPUE are either related to changes in vessel efficiency (through changes in q) or average stock density.

It is rarely the case that all vessels in a fleet are equally efficient, and the reliability of CPUE as an index of density and hence abundance would be enhanced if the effort exerted by each of the vessels fishing in a fleet could be standardised by accounting for differences in fishing power, so that q in equation 2 remains unchanged over time. These differences may result from, for example, varying vessel size or engine power among the vessels in the fleet. Neglecting to standardise effort by taking account of changes in fishing power would bias the relationship assumed between CPUE and abundance. This is particularly pertinent when there is a trend in the average fishing power of a fleet over time. Factors such as differences in technologies and varying skills of the skippers and crew of the vessels in a fleet may also account for differences in fishing power across the fleet.

4.2 Standardising effort by means of applying power factors

The framework for standardising effort was developed by Gulland (1956) and Beverton and Holt (1957). Gulland (1956) defined effort as the product of the fishing power of a vessel and an appropriate measure of the time spent fishing, where the fishing power of the vessel is determined by dividing the catch of that vessel by the catch of some standard vessel that fished over the same period of time. The standard vessel is generally one for which the greatest number of comparisons can be made with respect to catch per unit fishing time (Beverton and Holt, 1957). By knowing the power of the vessels in a fleet, the effort associated with each vessel in the fleet can be standardised, and the proportional relationship assumed between CPUE and abundance is not violated.

Certain vessel characteristics have been proposed as indices of fishing power. This proposal requires that the relationship between the vessel characteristic and fishing power be a proportional one. From their analyses of the English North Sea trawler fleet, Beverton and Holt (1957) concluded that gross tonnage was the most appropriate indicator of fishing power, and hence that effort could be standardised by multiplying gross tonnage by the amount of time spent fishing.

Gulland (1956) introduced the concept of modelling log CPUE by means of an analysis of variance (ANOVA) and following on from this, Robson (1966) applied a method of general multiple regression to estimate fishing power and relative stock abundance. The Robson method formed the basis for the first analysis conducted in South Africa by Newman *et al.* (1978) to calculate the fishing power of vessels in the South African purse-seine fishery. Conser (1984) undertook a study to compare a method developed by Honma (1974) for estimating effective fishing intensity and abundance indices, and which had been used extensively for the stock assessment analyses of tunas and billfishes, against that of Robson (1966) and found that on the whole the Robson generalised linear model was preferable on theoretical grounds.

General linear modelling is currently the most common framework within which CPUE is standardised. Hilborn and Walters (1992) provide two reasons in favour of the use of GLMs for standardising CPUE to provide a consistent index of abundance. First, GLMs help one understand the catching power of individual vessels, and secondly they correct for changing fleet composition. Hilborn and Walters (1992) do, however, warn against the use of GLMs if it cannot be assumed that catch rate is proportional to abundance, and highlight the fact that if there has been any change unrelated to the quantifiable effects in the model, the GLM will not be able to detect these and will ascribe them to changing abundance.

4.3 Standardising effort of the South African demersal fleet

There is limited information on the manner in which the power factors of the South African demersal fleet were originally calculated, other than an undetailed reference to the method of Beverton and Holt (1957). Reference is made in ICSEAF (1976) to the fact that the power factors of the demersal fleet were being studied by means of a computer program, and that the results indicated no identifiable trends in vessel characteristics that would influence fishing power. This report concludes that investigations into the power factors would continue (ICSEAF, 1976), but no further references relating directly to these studies could be found by the author of this thesis.

Andrew (1986) gives an abbreviated, but probably the most detailed report on the allocation of power factors for the South African demersal fleet fishing on the West Coast. She reports that a hypothetical 400 gross registered ton (GRT) side trawler was allocated a power factor of one. The fishing fleet was then divided into three broad categories, and power factors were allocated to each of the categories as shown in Table 4.

TABLE 4 : The power factors allocated to the South African West Coast demersal fleet.

GRT	Power Factor
300-600	1.14
800-1000	2.00
± 1700	2.80

Andrew (1986) points out that although the 400 GRT side trawler was allocated a power factor of one, the power factor of the GRT category into which it fell was slightly larger to allow for the fact that the mean catching power in that category was greater than that of the 400 GRT side trawler.

In addition to the above allocations of power factors to vessels fishing on the West Coast, R. Leslie (SFRI, pers. comm.) advises that the smaller inshore vessels (which fish mainly on the South Coast) were allocated a power factor of 0.9.

Andrew (1986) concluded that the above power factor allocation may not reflect the performance of the vessels in the fleet adequately, and recommended that further research was required on this topic. Andrew and Butterworth (1987) re-emphasized this point since they found that the management quantities of the hake assessments being conducted at the time were extremely sensitive to variations in the magnitude of the recent increasing trend in CPUE. They noted that the increasing CPUE trend could (to some degree) be a reflection of increasing trends in vessel efficiency, rather than of increases in abundance alone.

CHAPTER 5 - THE SFRI DEMERSAL DATABASE

5.1 Features of the database

Although the need for standardising the hake catch rate has long been acknowledged, the data have until recently not been available in an appropriate encoded format for standardisation to be performed. A lengthy process of converting data stored on various media (punch cards and magnetic tape) into the same format, amalgamating and validating them was undertaken. Once this process was complete it was possible to extract 17 years of data (covering the period 1978 - 1994), amounting to just over a million records (which included all ICSEAF Divisions and all species), to be used for such analysis. The data extracted from the demersal database for analysis purposes are listed in Table 5.

TABLE 5 : The information contained in the datafile used for analysis purposes (extracted from the demersal database).

Company code (a code assigned to each fishing company for identification purposes)
Vessel code (a code assigned to each fishing vessel for identification purposes)
Power factor (as crudely calculated in the early 1970s)
Vessel class (vessels were separated into broad categories according to their gross registered tonnage)
Landing date (Date on which the catch was landed at port)
Drag date (Date on which a drag took place)
Start time (Time (hour and minutes) at which drag started)
Effort (the amount of time net was dragged; recorded in minutes)
ICSEAF Division (identifying the Division in which the catch took place)
Grid block in which catch was taken (the fishing grounds are divided into 20 minute squares so that catch positions can be reported accurately)
Depth at which catch was taken
Mesh size used (75mm, 85mm or 110mm)
Species targeted
Total hake[2] catch (kg)
Total horse mackerel[2] (*Trachurus trachurus capensis*) catch (kg)
Total monk[2] (*Lophius upsicephalus*) catch (kg)
Total kingklip[2] (*Genypterus capensis*) catch (kg)
Total East Coast sole[2] (*Austroglossus pectoralis*) catch (kg)
Total West Coast sole[2] (*Austroglossus microlepis*) catch (kg)
Total snoek[2] (*Thyrsites atun*) catch (kg)
Total mackerel[2] (*Scomber japonicus*) catch (kg)
Total white squid[2] (*Loligo vulgaris reynaudii*) catch (kg)
Total red squid[2] (*Todapopsis eblanae/Todarodes angolensis*) catch (kg)
Total catch (kg) of other species[3] (e.g. ribbon fish (*Lepidopus caudatus*), panga (*Pterogymnus laniarius*))
Amount of hake (kg) which make up the large size category
Amount of hake (kg) which makes up the medium size category
Amount of hake (kg) which makes up the small size category
Amount of hake (kg) which makes up the fillets category
Latitude position at which catch was taken (minutes have been converted to decimalized minutes)
Longitude position at which catch was taken (minutes have been converted to decimalized minutes)

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[2]Space is provided in the log books for declaring the amount of each of these species caught. Apart from hake, the other species are referred to in this thesis as "declared bycatch".

[3]Space is not provided in the log books for declaring the catch of these species. The catch of each of these species is determined only at the landing site, and is apportioned across the drags of the trip in the same ratio of the catch of targeted species across drags. These species are referred to in this thesis as "undeclared bycatch".

The SFRI demersal database was designed to capture catch and effort information on a haul-by-haul basis, each record containing the position, duration and catch of a single demersal trawl. Skippers are obliged to fill in log books recording such information. However, due to operational constraints (e.g. vessels with factories on board prefer to keep the factories running continuously and therefore often empty their catch into the hold before the catch from the previous haul has been completely processed) it is not always possible to record the catch per trawl. In such cases the effort and position is recorded per trawl, whereas the catch for the day is logged against the effort of only one of the trawls (usually the last) for the day. Zero catch is recorded against the other trawls completed during that day. The demersal database therefore contains catch information reported at two levels of resolution, *viz* daily and drag tallies, with the majority of reporting being at the drag level (the number of drags containing daily tallies range between 4 and 28% per annum over the period under consideration).

Because of the practice of the daily tallies as explained above, it was considered necessary to accumulate the data on a daily basis for each vessel before attempting GLM analyses. Failure to do so would have led to effort being allocated erroneously. For example, the effort exerted on the last drag of the day would be allocated to the total catch of the day if the daily tally method of reporting was employed and the data were not accumulated; this would result in an artificially high CPUE for that particular drag, and erroneous zero CPUE values for the other drags.

Another complication that required the accumulation of the data over a day is that skippers often average the catch taken on a day over the number of drags completed on that day, with rounding error (if any) included in the catch allocated to the last trawl of the day. Examples of the various methods of reporting catches are shown in Appendix A.

5.2 Separation of the database into drag and daily files

It was assumed initially that the daily or drag tally method of reporting catches was consistent across a trip, and the database was therefore separated into a drag file and a daily file (the drag file including catches recorded on a drag tally basis, and the daily file including catches recorded on a daily tally basis) prior to the data being accumulated over a day.

5.3 Identifying potential coding errors in the drag and daily files

In a dataset as large as the demersal one it is inevitable that typographical errors will occur and it was therefore deemed necessary to attempt to remove erroneous records prior to conducting analyses. It is not always easy to detect typographical errors, especially in large datafiles, and only those records that appeared to contain extreme values with respect to certain of the variables were identified and excluded.

The approach to removing potential typographical errors is not without its own possible problems. What is removed could be a genuine independent observation from a heavy tailed distribution, which has potential large and important influence when other factors are estimated in fitting a GLM. Ideally, GLMs should be fitted first, and such observations removed on the basis of reflecting large residual values (rather than large differences from central values of nominal (unstandardised) data). However, in this case, different sets of analysts were evaluating the data, making it essential that the same dataset was used by all parties to facilitate comparisons (see Chapter 7). This necessitated early elimination of possible coding errors, precluding the option of GLM-based exclusion criteria which would have differed between different GLMs fitted. The exclusion procedure does not introduce any major bias into the estimates of primary importance. This is illustrated below where the slope statistics are reported for West Coast hake for a) a model including a year factor only, and b) the final full model (see Chapter 10). Each of these runs were carried out on the dataset which included the potential coding errors, and on the dataset from which the potential coding errors had been removed.

Model	Likely Coding Errors	Slope
Year only	included in dataset	3.0%
Year only	removed from dataset	3.7%
Full	included in the dataset	-1.2%
Full	removed from the dataset	-0.4%

There is virtually no difference between the differences in the slopes for the year only model (0.7) and the full model (0.8) for the two datasets considered, i.e. the removal of potential coding errors has about the same effect on the results with or without standardisation so that the removal of potential coding errors prior to conducting the analyses makes little difference to the results of consequence.

Since the drag file includes information on a drag basis, it was possible to identify and remove drags containing potential coding errors prior to the accumulation of the data. Rather than making a subjective decision as to a cut-off point above which any values could be considered erroneous, a more objective method - the "quantile rule" - was applied. At a drag level those records which contained any effort values less than the 1% quantile or greater than the 99% quantile for effort were considered potentially erroneous with respect to the effort recorded, and were subsequently excluded. In addition, a number of drags had zero total catch, but positive effort recorded. These were assumed to indicate that problems had occurred with the net on that haul, and the drag was therefore eliminated. Some drags had a dummy depth recorded (0 or 999) and these records were also deleted.

It was not possible to identify and remove coding errors on a drag basis in the unaccumulated daily file, since deleting any drags for a particular day would bias the CPUE data (given the manner in which catches and effort are reported).

For both the drag and daily files prior to accumulation, data recorded for foreign and Namibian vessels (vessel code $\geq$ 500) were removed.

5.4 Accumulation of the data

Since the method of reporting catches required that the data be accumulated over a day for each vessel fishing on that day, a number of decision criteria were necessary to accumulate the data. It was found that, on average, three drags took place per day and this fact was used as the basis for the decision criteria adopted.

- If fishing took place in more than one Division within a day, the data were allocated to the Division in which at least two thirds of the drags took place. If there was no such "two thirds majority", the records were ignored.

- Different net mesh sizes (75mm, 85mm and 110mm) are used in the fishery. The net mesh size which was used on at least two thirds of the drags was allocated to that day. If there was no such "two thirds majority", the mesh size was recorded as missing. Two records in the entire database had a mesh size of zero recorded. In both cases, 110mm was used on all other trawls of the day. Therefore a mesh size of 110mm was assumed for those two records.

- The targeted species were separated into two broad categories, hake (H) and other (O). The species that was targeted in at least two thirds of the drags was the target species allocated to that day. If there was no such "two thirds majority", the target species was recorded as missing.

- Depth, latitude and longitude were averaged over the values provided for that day.

Thus the data in each file were accumulated over a day for a given vessel, summing over the catches and effort, and averaging over the depth, latitude and longitude. The accumulated files also included the Division, mesh size and target species as determined by the decision criteria above. It was then possible to separate out the West and South Coast data as identified by the ICSEAF Division code, where the West Coast is identified by Division 1.6 and the South Coast is identified by Divisions 2.1 and 2.2.

Although potential coding errors had been removed from the drag file prior to accumulation, suspiciously large values within the accumulated drag file were identified and removed before attempting any analyses. Since the effort had been accumulated over a day, it was considered necessary to determine whether any unrealistically high effort values still existed (on a day basis). These were identified as being any effort values greater than the 99% quantile for effort. Furthermore, any records containing CPUE values greater than the year-specific 99% quantiles for CPUE were also considered erroneous and therefore excluded from the analyses.

The reason for making the CPUE constraints year-specific is because there may be trends in CPUE with time. Furthermore, larger vessels are able to take a larger catch, and if the CPUE constraints were not year-specific, a disproportionately large fraction of the catch rate data from these larger vessels in the years of higher overall catch rates would be inappropriately considered errors, hence biasing time trends estimated from the data. There has been a move from targeting hake to targeting bycatch in more recent years, which also argues for a year-specific basis for error identification.

The 99% quantile for effort was calculated to be 890 minutes and any days with effort greater than this were excluded from the analyses. The year-specific 99% quantiles for hake CPUE are shown in Table 6. For those models which include the declared bycatch CPUE (see footnote to Table 5 for definition) as an explanatory variable, year-specific 99% quantiles for bycatch CPUE were calculated and values greater than these (Table 6) were excluded from the analyses.

Only those days on which hake was recorded as the target species were included in the analyses. Although skippers may have in some cases recorded non-hake targeted catches as hake targeted, this was considered the most appropriate approach given that the target data in the database are the only recorded data to bring to bear on this issue.

TABLE 6 : Year-specific 99% quantiles for hake and declared bycatch CPUE determined from the accumulated West Coast hake drag file. Any records with CPUE greater than these annual 99% quantiles were excluded from the West Coast hake CPUE analyses.

Year	99% quantile for hake CPUE (kg/minute)	99% quantile for bycatch CPUE (kg/minute)
1978	54.29	19.14
1979	68.35	24.84
1980	55.45	17.90
1981	55.08	14.55
1982	58.36	9.91
1983	68.81	16.34
1984	93.86	21.61
1985	82.82	23.91
1986	104.02	24.98
1987	85.20	30.95
1988	91.14	35.73
1989	96.01	37.76
1990	130.05	43.53
1991	115.29	49.25
1992	103.29	45.69
1993	130.12	50.99
1994	136.88	28.44

5.5 The vessel characteristic database

In addition to the demersal database, a vessel characteristic database exists which includes information on the various features of the vessels in the fishery, e.g. vessel length, horse-power, gross tonnage, etc. These data were collected by means of a questionnaire that was sent to the Industry, but many of the questionnaires were not completed in full. Information regarding the propeller type and presence or absence of a nozzle was lacking for many vessels, and a default of fixed propeller and no nozzle was therefore assumed where required. It was not possible to make any assumptions about the rest of the information not provided in the questionnaire, and these data were therefore not considered for inclusion as explanatory variables in the GLM. Table 7 lists all the information captured in the vessel characteristic database.

TABLE 7 : The information captured in the vessel characteristic database.

Company code (a code assigned to each fishing company for identification purposes)
Vessel code (a code assigned to each vessel for identification purposes)
Year in which the vessel was built
Year and month in which the vessel started fishing
Year and month in which the vessel stopped fishing
Vessel length
Gross tonnage
Gross propulsion (recorded in horse power)
Gross propulsion (recorded in kilowatts)
Shaft propulsion (recorded in horse power)
Shaft propulsion (recorded in kilowatts)
Propeller type (fixed or variable)
Kort nozzle (absent or present)

Of the information available in Table 7, vessel length was the characteristic for which information was most complete (77% of the records had a vessel length recorded). Barring the shaft propulsion information for which there was only a 30% record rate, on average 74% of the records included information on gross tonnage, gross propulsion, propeller type and kort nozzle.

5.6 Data reliability in the context of GLM analyses

Some of the data recorded in the demersal database are not considered to be suitable explanatory variable candidates for the GLM analyses because of concerns about their accuracy. In particular, the mesh size information and the catch of the undeclared bycatch species are considered unreliable.

5.6.1 Mesh size

Since 1975, the legal minimum mesh size for catching hake on the West Coast has been 110mm. In the late 1970s and in the 1980s (and perhaps even in the early 1990s) extensive illegal use was made of liners, thereby greatly reducing the mesh size. The Industry has recently justified their past use of liners by claiming that the effects of implementing the increase in the minimum mesh size imposed by ICSEAF would have meant a drop in catch rates to levels that were uneconomical (Bergh and Barkai, 1996a). To support this contention, Bergh and Barkai (1996a) report that the only company that adhered to the 110mm minimum mesh size went out of business. Because it was illegal to use liners, skippers recorded the mesh size in the log books as 110mm, regardless of the actual mesh size used, hence rendering the mesh size information in the database unreliable. The Industry claims to have stopped using liners over the past few years because market demand focuses now on quality rather than quantity of fish. The Industry has recently provided a range of possible years (based on the results of an Industry-initiated questionnaire directed at experienced persons in the demersal fishery) over which the use of liners was believed to have been phased out (South African Deep-sea Trawling Industry Association, 1998), but given the diversity of this range, the information cannot be used in any quantitative manner.

5.6.2 Bycatch species identification

Skippers are required to record the catches of all targeted species in the drags. In the early years provision was made in the log books for the declaration of three target species: hake, horse-mackerel and sole. This did not pose a problem because the fishery predominantly targeted these species (hake on the West Coast; sole and horse-mackerel on the South Coast). As the fishery changed to a more mixed-species nature, allowance was made eventually for the declaration of other commercially important species, i.e. kingklip, snoek, red and white squid, monk and mackerel (these species, along with sole and horse-mackerel constitute the "declared bycatch species"). However, catches of other species for which no allowance was made in the log books were also being made, e.g. ribbon-fish, panga (these are examples of the "undeclared bycatch species"). Because no provision was made to declare these species in the log books, the total catch of each of these species was recorded only at the end of the trip when the fish were off-loaded and the catches weighed. The total catch of each of these species was then apportioned across the drags of the trip according to the proportion of the total catch of the target species for that trip. The implication of this is that the catches of these undeclared species are assigned across all trawls, even if they were not caught on a particular trawl, and they are correlated with the catches of the target species, which in the case of the West Coast is predominantly hake. To give an example, on a trip of 15 drags, if 10 of those drags were hake targeted, and the other five horse-mackerel targeted, the hake catches of the 10 hake directed drags and the horse-mackerel catches of the 5 horse-mackerel directed drags would be added together to yield a total targeted catch. The undeclared bycatch species would then be apportioned across the drags in the same ratio as the contribution of the target species catch per drag to the total target species catch for that trip.

Given these complexities associated with the recording of mesh size and the undeclared bycatch species, these data are not considered to provide suitable explanatory variable candidates for the GLM analyses.

CHAPTER 6 : TRENDS IN THE WEST COAST DATA

6.1 Historic CPUE

The CPUE time series used in earlier West Coast hake assessments (Table 1) was calculated by dividing the total hake catch for any given year by the total standardised effort for that year. The effort was standardised by applying power factors that were crudely calculated in the early 1970s (see Table 4), and that are probably no longer appropriate. This CPUE series indicates that the West Coast hake resource has increased by 33% over the period 1978 - 1994 (Figure 4), a 1.7 % increase in abundance per annum.

6.2 Catch and nominal effort

It should be noted that the nominal effort referenced below is not the same as the effort reported in Table 1 for two reasons. In Table 1 the CPUE is calculated by dividing the directed hake catch by directed (standardised) hake effort, and the total hake catch (regardless of the species targeted) is then divided by the CPUE to yield an effective effort value, i.e. the effort that would be required if all hake was caught by hake targeted fishing, and it is this effort that is recorded in Table 1. The effort referenced in this Section is the actual recorded (nominal) effort, i.e. the amount of time (recorded in minutes) that the net was towed through the water, which also reflects no adjustment for power factors as in Table 1.

Hake catch (kg) as a proportion of total catch (kg) per annum is shown in Figure 5, where total catch is the sum of hake, declared and undeclared bycatch catches. Figure 5 also shows the amount of effort (minutes) directed at hake (obtained from "species targeted" information in the demersal database) as a proportion of total effort exerted on an annual basis.

The proportion of effort directed at hake each year remained fairly constant until 1989 (approximately 100%), after which it declined, although 1994 reflects an increase in the amount of effort exerted on hake. Hake catches declined over the period 1987 - 1989 (see Table 1) even though the amount of effort directed at hake remained approximately 100%. The reason for this surprising feature is that no provision was originally made in the log books for recording target species other than hake, horse-mackerel and sole. Hence, any targeting on species other than the three provided in the log books were generally recorded as hake targeted. The decline in the proportion of effort directed at hake since 1989 coincides with the time that provision was made in the log books for the declaration of a wider variety of target species. The increase in the proportion of hake caught and effort expended on hake in 1994 may be reflecting a shift towards targeting hake again.

6.3 Depth

For hake targeted catches in Division 1.6, the average depth fished per year is shown in Figure 6. This series is derived by applying the equation

$$\overline{d_y} = \frac{\sum_d d * E_{d,y}}{\sum_d E_{d,y}} \qquad (3)$$

where d is the depth at which fishing took place, and

$E_{d,y}$ is the actual effort (minutes trawled) exerted in year y at depth d.

From Figure 6 it is evident that there has been a move to fishing for hake in deeper waters in the later years of the period considered.

CHAPTER 7 - GLM ANALYSES OF THE WEST COAST HAKE CPUE SERIES

7.1 Introduction

At the outset of this project it was decided that the accumulated drag file (described in Chapter 5) be used for analysis purposes. The reason for excluding the daily file from the analyses was that it was not possible to remove potential coding errors from those data in the same manner as for the drag file prior to accumulation. The accumulated daily file would, however, be used to determine the sensitivity of the model to the inclusion of these data.

It was important that the same datafile be agreed by the Industry as the baseline datafile on which to perform analyses. This agreement was necessary because the Industry consultants would also be performing various analyses, and if they used a different datafile it would be difficult to determine the source of the differences between Industry and SFRI results. If the datafile used by both parties is the same, the reasons for any differences in the results that might eventuate can be narrowed down to differences in the models applied or to the way in which the data are treated (both of which are easier to identify than are differences arising from the use of different datafiles).

Note that it is normally the case for GLMs that the inclusion/exclusion of explanatory variables in the model is based on statistical tests of significance. In this thesis, however, the selection is generally determined rather by improvement in the r^2 statistic. The reason for this is that for very large datasets factors can be statistically significant, but nevertheless have a minimal impact on predictions - hence the extent of improvement in r^2 is often used instead as a basis for deciding the inclusion/exclusion of candidate explanatory variables (to give the reader an idea of the number of data points in each of the datasets used in the various analyses, those for the West and South Coast hake approximate 150 000 and 70 000 respectively, and those for the West and South Coast rock lobster approximate 35 000 and 20 000 respectively). The r^2 statistic, however, is necessarily improved as additional explanatory varaibles are added to the model, and an objective criterion of deciding the inclusion/exclusion of explanatory variables in the model would be desirable. For example, New Zealand scientists apply the following stopping rule

(Doonan, 1991). A stepwise regression is applied where each variable is regressed alone, and the one with the lowest residual variance is selected, resulting in this variable being the first to be admitted to the model which includes all the variables that are to be retained. Then, from the remaining unadmitted variables, the one which results in the lowest residual variance when included in the model fit is selected. This process continues until the residual variance falls within x% of the residual variance for the full model. Doonan (1991) selected x to be 6%, and states that this was an arbitrarly chosen value.

Strictly the adjusted r^2 (i.e. r^2 adjusted for degrees of freedom) is a better statistic to use in a model selection process, where adjusted $r^2 = 1 - (1 - r^2)(n - 1)/(n - m)$, n being the number of observations, and m the number of variates estimated. However, Snedecor (1946) points out that for large samples (as for the cases considered in this thesis) the fraction (n-1)/(n-m) differs little from 1 and the adjusted r^2 is thus approximately equal to r^2. To illustrate this, adjusted r^2 statistics are shown below alongside the r^2 for each of the final models for each fishery considered in this thesis. It is clear in nearly all cases that there is little difference between the two statistics; furthermore the substitution of r^2 by adjusted r^2 would have no impact on model selection decisions in the cases considered in this thesis.

Model	r^2	Adjusted r^2
West Coast hake	29.5%	29.4%
South Coast hake	31.2%	31.0%
West Coast rock lobster	70.5%	70.4%
South Coast rock lobster	25.2%	24.3%

The actual decisions with respect to the inclusion of particular factors in the GLMs (both for hake and rock lobster) were made by the members of the working groups, to whom the work reported in this thesis was presented, as time progressed. Viewed in hindsight, these decisions do not always reflect consistent application of identical criteria, but it should, however, be appreciated that such decisions often reflected compromises between opposing views in the context of a wider debate at the time concerned.

7.2 The initial base case

An initial base case for modelling the West Coast hake CPUE (henceforth referred to as base case (1)) was proposed of the form:

$$ln(\text{CPUE}+\delta) = \alpha+\beta_{year}+\omega_{season}+\eta_{depth}+\lambda(vessel\ length)+\lambda'(vessel\ length)^2+\upsilon_{nozzle}+\kappa_{prop}+\epsilon \quad \textbf{(4)}$$

where CPUE is the catch in kilograms per minute trawled,

δ is a constant added to CPUE (see Section 7.4) to allow for the occurrence of zero CPUE (in this case taken to be 50% of the average nominal hake CPUE),

α is the intercept,

year is a factor with 17 levels (covering the period 1978 - 1994),

season is a factor with 4 levels:

Summer = December - February
Autumn = March - May
Winter = June - August
Spring = September - November,

depth is a factor with 4 levels:

$d1 \leq 100$m
$100\text{m} < d2 \leq 200$m
$200\text{m} < d3 \leq 300$m
$300\text{m} < d4 \leq 400$m
$d5 > 400$m,

vessel length is a continuous variable upon which the response variable is taken to depend quadratically,

nozzle refers to whether a kort nozzle is present or absent, *prop* refers to the propeller type which is either fixed or variable, and

ϵ is the error term which is assumed to follow a normal distribution.

Depth was treated as a categorical variable since initial investigations indicated that treating dependence upon it as a simple linear form was inadequate.

A high level of correlation was observed between the various size and power characteristics associated with each vessel so that only one of these variables was included. Vessel length was the one selected since it was the piece of information in the vessel database that was most complete. However, after matching up the vessel information from the vessel characteristic file with the vessels in the accumulated drag file, some 12% of the data were still then excluded from the analyses since vessel length information was not available for that proportion of vessels.

The presentation of base case (1) (n = 98924) and preliminary results to the Industry resulted in their consultants arguing that vessel length was not sufficient to on average capture the performance of a particular vessel or class of vessels (Bergh and Barkai, 1996a), and they suggested that a vessel effect for each individual vessel rather be included in the analyses. Given this, propeller type could be excluded from the model since no vessel had changed propeller type over the time series and the vessel effect therefore subsumed the effect of the propeller type (Butterworth, 1996b). Kort nozzle, however, could be retained since a few vessels had kort nozzles fitted during the period under consideration. The inclusion of each vessel as a separate effect in the model (as opposed to vessel length) means that many more parameters have to be estimated, but this was not considered problematic given that there is a sufficient amount of data for each vessel.

A revised model was therefore suggested and is discussed below.

7.3 The interaction-free base case

Taking into account the comments made regarding the vessel effects, and including two further explanatory variables that had not been considered earlier, base case (2) was defined as follows:

$$ln(\text{CPUE}+\delta) = \alpha+\beta_{year}+\omega_{season}+\eta_{depth}+\tau_{lat}+\lambda_{vessel}+\upsilon_{nozzle} + \gamma(bycatch\ CPUE)+ \epsilon \qquad (5)$$

where new quantities are

lat - a factor with four levels referring to latitude :

$l1 \leq 31°00'S$

$31°00'S < l2 \leq 33°00'S$

$33°00'S < l3 \leq 34°20'S$

$l4 > 34°20'S$

(latitude was included in the model to account for the possibility that there had been a longshore as well as offshore (reflected by the depth variable) shift in fishing pattern over time),

vessel - a factor with 101 levels, where each vessel is identified by the vessel code, and

bycatch CPUE - a continuous variable relating to the catch rate of the declared bycatch species.

The inclusion of the nozzle term in the model required that the datafile be merged with the vessel characteristic file. For consistency, those records for which vessel length was not recorded continued to be excluded from the analyses.

7.4 The selection of δ

δ is a (usually small) constant added to CPUE to allow for the occurrence of zero CPUE values, which would otherwise cause problems when taking the log of CPUE. Numerous approaches have been adopted for selecting a value for δ. At ICCAT it was practice at one time to set δ equal to 10 times the largest CPUE value in the dataset being analysed, but this was revised to δ being set equal to 10% of the mean CPUE values in the dataset (ICCAT, 1995). Campbell *et al.* (1995) report that the selection of δ (z as they refer to it) is somewhat arbitrary, and give as an example that δ can be set to the smallest positive catch rate for the data being analysed. As the scale for CPUE values is essentially arbitrary, the choice of δ must be linked to the scale adopted. In fisheries, this is usually achieved by defining δ to be some percentage of the overall nominal mean. This approach has been followed here, although it does have the disadvantage that in absolute terms, the value of δ changes slightly each year given the inclusion of additional data in the dataset which leads to a change in the average nominal CPUE value.

For this study, initially the selection of δ was based on the requirement of (near-) normality of the residual distribution obtained from the model fit. A basic assumption in standard general linear modelling is that the residuals (the difference between the actual data and the relationship fit through them by the model) are normally distributed. Therefore, a number of runs were carried out to determine a value of δ that yielded residuals that were closest to being normally distributed; a δ of 50% of the mean CPUE gave the best result (see Table 12 in Section 7.8 which tests for sensitivity to the choice of δ for the model that includes interactions and was applied to the dataset available at the time). This was determined by examining the degree of kurtosis (heaviness of the tails) and skewness, with emphasis being placed on obtaining a low value for the skewness statistic. A normal distribution has a zero value for both kurtosis and skewness (Snedecor, 1946; Zar, 1984).

Subsequently, however, for reasons associated with reducing bias linked to attempts to correct for bycatch (see Chapter 8, particularly Section 8.7), the δ value selected was taken to be 10% of the average hake CPUE. Figure A and Table A in the Output Appendix show the distribution of unstandardised residuals and associated summary statistics respectively for the final model and final dataset used. These indicate that the distribution is skewed to some extent. However, in this context distribution normality pertains primarily to drawing inferences about precision (confidence intervals) of individual estimates, whereas in this case such information has not been used in the population models subsequently applied. It is the trend estimates for the standardised CPUE that have a marked influence on the results from such models, so that the most important concern is to reduce bias in such estimates. This was the primary reason for the final choice of δ made in Chapter 9. Some argue, (e.g. Mead, 1988) that very small values of δ are to be preferred. However, adoption of this position here would result in an even further skewed distribution of residuals - see Figure B and Table B in the Output Appendix, where δ is assumed to be 0.001. Note that for this last case, the zero (and near-zero) CPUE observations lead to a bimodal residual distribution, whereas this bimodality disappears for the larger δ value chosen for Figure A.

In summary, the chioce of δ was based on a compromise between reducing bias on the one hand (suggesting a low δ), and maintaining residuals as close to normally distributed as possible on the other (requiring a high δ). The final selection of δ = 10% of the average hake CPUE was made in this context.

7.5 Standardising the CPUE

The method of calculating the annual standardised CPUE is more complicated than simply assuming that annual abundance is proportional to the exponentiated year factor, as suggested by Kimura (1981), for example. This complication arises as a result of the inclusion of δ which introduces non-linearity in the log-transformed CPUE, and which therefore needs to be factored out when standardising the annual CPUE (since it is assumed that fish density is proportional to CPUE, and not CPUE+δ). This is achieved by applying equation 6 and assuming conditions pertinent to "average" fishing; hence the following choices: average season = *autumn*, average depth = *d3*, average latitude = *l2*, average vessel is the median of the vessel factor estimates, there is predominantly no nozzle and the bycatch CPUE is the average of that recorded over the period.

$$\mathrm{CPUE}_{year} = e^{(\alpha + \beta_{year} + \text{average season} + \text{average depth} + \text{average lat} + \text{median vessel estimate} + \gamma^{*}(\text{average bycatch CPUE}))} - \delta \qquad \textbf{(6)}$$

7.6 A stepwise approach to determine the relative importance of the explanatory variables in the interaction-free base case

The explanatory variables considered in base case (2) can be separated into four categories

- a year factor,
- environmental factors,
- vessel-related factors, and
- other factors.

The environmental factors consist of season, depth and latitude, the vessel-related factors consist of the nozzle factor and a factor for each individual vessel, and other factors refer to the catch rates of the declared bycatch species.

The following subsets of base case (2) were evaluated to determine the relative importance of the explanatory variables in the model:

(1) $ln(\text{CPUE}+\delta)$ = year

(2) $ln(\text{CPUE}+\delta)$ = year+environmental factors

(3) $ln(\text{CPUE}+\delta)$ = year+environmental factors+vessel-related factors

(4) $ln(\text{CPUE}+\delta)$ = year+environmental factors+vessel-related factors+other factors

Model (4) is synonymous with base case (2) as set out in equation 5, and for this model n = 98023 since the 99% quantile exclusion rule is applied to the bycatch CPUE data (see page 41). For each model the r^2 and slope statistic is reported, as well as the number of parameters estimated (p) for each model considered. The results of each of these models are shown in Table 8.

TABLE 8 : Results from base case (2) and subsets thereof applied to the West Coast hake CPUE data.

Model	r^2	Slope	p
ln(CPUE+δ) ~ Year	5.81%	3.20%	17
ln(CPUE+δ) ~ Year + Depth + Season + Lat	12.75%	2.50%	27
ln(CPUE+δ) ~ Year + Depth + Season + Lat + Vessel	25.19%	0.89%	127
ln(CPUE+δ) ~ Year + Depth + Season + Lat + Vessel + Nozzle	25.25%	0.76%	128
ln(CPUE+δ) ~ Year + Depth + Season + Lat + Vessel+ Nozzle + Bycatch CPUE (base case (2))	26.10%	0.96%	129

These results indicate that as each subset of explanatory variables is added to the model, so the slope of the standardised CPUE is reduced (except in the case of including the declared bycatch CPUE in the model). The environmental factors have an impact on the explanatory power of the model (r^2 increases from 5.8% to 12.8%), whereas the slope of the standardised CPUE is reduced from 3.2% to 2.5%. Including a vessel effect in the model improves r^2 considerably (from 12.8% to 25.2%) and makes a substantial difference to the slope of the standardised CPUE (a drop from 2.5% to 0.9%). The inclusion of the nozzle factor makes little difference to the results, both in terms of the explanatory power of the model (r^2) and the slope. However, when making allowance for the catch rate of other species, r^2 increases marginally to 26.1% and the slope increases from 0.8% to 1.0%.

7.7 Models with interactions

Models with the same main effects as in equation 5, but including interactions which make allowances for spatial density patterns which changed over time were also investigated. The interactions therefore considered were *year*depth, year*latitude, depth*latitude* and a combination of all three.

The introduction of interactions with year requires that the standardised CPUE (assumed to provide an index of local density) be integrated over area to determine an index of abundance. In fact, those models without interactions should also strictly be integrated over area, but the area term would essentially be a constant. Given that there are interactions, the formula applied to standardise the CPUE becomes

$$CPUE_y=\Sigma_{strata}\left[e^{(\alpha+\beta_{year}+(\text{average season})+\text{depth}+\text{lat}+\text{median vessel estimate}+\gamma*(\text{average bycatch CPUE})+\text{interactions})}-\delta\right]*A_{stratum}/A_{total} \tag{7}$$

where $A_{stratum}$ is the size of the stratum (e.g. depth 200-300m and latitude 31 - 33°), and A_{total} is the total size of the area considered (it is not strictly necessary to divide by A_{total}, but it keeps the units and size of the standardised CPUE index comparable with those of the basic CPUE data).

The area sizes for the depth/latitude combinations for the West Coast are shown in Table 9.

TABLE 9 : The sizes of the areas (nm²) covered by each of the latitude/depth combination strata on the West Coast. The percentage contributions of each stratum to the total area are shown in brackets.

	Depth (m)				
Latitude (S)	0-100	101-200	201-300	301-400	401-500
≤ 31°00	906.84 (2.82%)	6712.13 (20.86%)	3597.79 (11.18%)	800.68 (2.49%)	657.12 (2.04%)
31°00-33°00	1179.97 (3.67%)	3383.32 (10.51%)	2842.35 (8.83%)	2382.84 (7.41%)	1426.62 (4.43%)
33°00-34°20	1052.23 (3.27%)	993.57 (3.09%)	882.33 (2.74%)	458.3 (1.42%)	500.59 (1.56%)
>34°20	933.14 (2.90%)	2225.33 (6.92%)	600.09 (1.86%)	356.35 (1.10%)	286.83 (0.89%)

The following interaction models were considered (note that the numbering of these models continues on from those of base case (2)):

(5) base case (2) + *year*depth* interaction

(6) base case (2) + *year*lat* interaction

(7) base case (2) + *depth*lat* interaction

(8) base case (2) + *year*depth* + *year*lat* + *depth*lat* interactions

The results of these models are shown in Table 10.

TABLE 10 : Results from base case (2) including interactions applied to the West Coast hake CPUE data. Two slope statistics are quoted: a) for all depth ranges and b) for depth ranges > 200m. Option a) requires that linear interpolation be applied to fill empty cells since fishing did not take place in the 0 - 100m depth range in some years, whereas option b) considers only depths > 200m (and is therefore independent of the linear interpolation assumption).

Model	r^2	a) Slope	b)Slope	p
ln(CPUE+δ) ~ base case (2) (from Table 8)	26.10%	0.96%	0.96%	129
ln(CPUE+δ) ~ base case (2) + *year*depth*	27.38%	-2.33%	0.08%	186
ln(CPUE+δ) ~ base case (2) + *year*lat*	26.80%	0.96%	0.93%	177
ln(CPUE+δ) ~ base case (2) + *depth*lat*	26.71%	1.04%	1.03%	141
ln(CPUE+δ) ~ base case (2) + *year*depth* + *year*lat* + *depth*lat*	28.57%	-2.61%	-0.24%	246

The implementation of the *year*depth* interaction model requires explanation. Empty cells exist for this model because no fishing took place in the 0 - 100m depth zone in certain years. A decision was therefore necessary to fully define the calculation to be applied for standardising the CPUE. The abundance index was accordingly computed in two ways:

a) for all depth ranges, filling in missing cells by means of linear interpolation, and

b) for depths > 200m.

The rationale behind option b) is that although the area from 0 - 200m makes up a substantial portion (54%) of that below 500m, very little fishing (some 2% of the hauls) takes place at depths below 200m. The majority of hauls within the 0 - 200m depth range occur very close to the 200m depth contour, and accordingly are of questionable representativeness of densities within the whole depth-latitude stratum to which equation 7 would take them to refer.

Although option b) excludes part of the range of hake distribution, its results are considered to be more reliable given that it is free of the interpolation assumption.

7.8 Sensitivity analyses

The results from the various models considered in Sections 7.6 and 7.7 were presented to the Industry in July 1996. It was agreed that Model 8 was the most appropriate model to consider in future analyses (based on the r^2 statistic), and this model is henceforth referred to as base case (3). It was also agreed that option (b) be employed for standardising the CPUE.

Various issues were raised by the Industry that required further investigation. These related to the fact that the Industry claimed that bycatch catches are seasonal, and no provision was made for this in base case (3). Furthermore, the Industry pointed out that skippers are able to target particular species, and that undeclared bycatch species were becoming increasingly important, e.g. ribbonfish. It was therefore agreed that the following factors would be considered for inclusion in base case (3):

- the bycatch catch rate of undeclared bycatch species (given that these bycatch species were becoming increasingly important),
- a *bycatch*season* interaction (given that bycatch catches are seasonal, e.g. snoek are caught from July - September),
- a *bycatch*depth* interaction (given that skippers can target particular species at various depths e.g. ribbon-fish are targeted at depths of 250m), and
- a *depth*season* interaction.

Because the catches of the undeclared bycatch species are apportioned across the drags of a trip according to the ratio of target species caught on the trip, a direct correlation exists between the hake catch and the amount of undeclared bycatch caught. Therefore, in order to include the undeclared bycatch in the model, the total undeclared bycatch catch rate for the trip was used as a predictor variable associated with the undeclared bycatch at a drag level.

The results for these models are shown in Table 11.

TABLE 11 : Results from variants of the West Coast hake base case (3) model. These models relate to the various issues raised by the Industry with respect to the targeting of bycatch, i.e. that undeclared bycatch was becoming increasingly important to the Industry, that bycatch catches tend to be seasonal, and that skippers are able to target bycatch by fishing at select depths.

Model	r^2	Slope	p
Base Case (3)	28.57%	-0.24%	246
Base Case (3) + *undeclared bycatch*	28.57%	-0.25%	247
Base Case (3) + *undeclared bycatch+ bycatch*season*	29.11%	-0.25%	250
Base Case (3) + *undeclared bycatch+ bycatch*depth*	28.94%	-0.11%	251
Base Case (3) + *depth*season*	29.70%	-0.20%	258

For the models that include interactions with season, a mean standardised CPUE for a specific year was calculated by summing over the depth and latitude strata within a year and season, and then summing over the four seasons and taking an average. Hence:

$$CPUE_{year} = [\Sigma_{strata}\Sigma_{seas} (e^{(\mathrm{Intercept} + \beta_{\mathrm{year}} + \mathrm{season} + \mathrm{depth} + \mathrm{lat} + \mathrm{median\ vessel\ estimate} + \gamma * (\mathrm{average\ bycatch\ CPUE}) + \mathrm{interactions})} - \delta)*A_{stratum}/A_{total}]/4 \qquad \textbf{(8)}$$

where $A_{stratum}$ and A_{total} are as for equation 7.

The results indicate that most of the additional factors included in the model make little difference to both r^2 and the slope. The only model that had a non-negligible but nevertheless slight effect on the results was the one that included a *bycatch*depth* interaction, yielding a slope of -0.11% as opposed to -0.24% calculated for base case (3). The effect of including the bycatch rate of undeclared species as an explanatory variable in the model was not statistically significant.

Further sensitivity tests were conducted and these included omitting the nozzle term from the base case (n = 111642), including the daily file data in the analyses (n=120917), assuming a finer latitudinal breakdown, and assessing the sensitivity of the model to various δ values.

Recall that including the nozzle factor in the model requires that the data file be merged with the vessel characteristic file, and that in this process some 12% of the data are lost. By excluding the nozzle term, the data that were previously excluded from the analyses could be retained.

The breakdown of latitude into 4 components for the base case was subjectively selected on the basis of where it was thought that most fishing activities occurred : two areas north of Cape Columbine (approximately 2 degree blocks each), Cape Columbine to Cape Point, and south of Cape Point (approximately 1 degree blocks each). The sensitivity of this was tested by refining the latitude divisions to 1 degree blocks, except in the case of the extremes where the blocks are slightly bigger than 1°. The finer latitudinal breakdown was thus:

$lat1 \leq 30°00'S$
$30°00'S < lat2 \leq 31°00'S$
$31°00'S < lat3 \leq 32°00'S$
$32°00'S < lat4 \leq 33°00'S$
$33°00'S < lat5 \leq 34°00'S$
$lat6 > 34°00'S$

Sensitivity to the value of δ was tested by assuming it to be 10% and 100% of the average nominal hake CPUE respectively.

The results of these various sensitivity tests are shown in Table 12; the results from base case (3) (where δ is taken to be 50% of the average hake CPUE) are included in this Table as a reference point.

TABLE 12 : Results from further sensitivity analyses of the West Coast hake base case (3) model. These relate to testing the sensitivity of the model to the value of δ, the inclusion of the daily file data, excluding the nozzle factor and considering a finer latitudinal scale. Skewness and kurtosis statistics are quoted for the models which consider various δ values, a value of 0 (Snedecor, 1946 ; Zar, 1984) for each being consistent with residuals which are normally distributed.

Model	r^2	Slope	p	Skewness	Kurtosis
Base Case (3) (δ = 10% of mean CPUE)	27.9%	-0.46%	246	-0.53	0.68
Base Case (3) (δ = 50% of mean CPUE)	28.6%	-0.24%	246	0.06	0.16
Base Case (3) (δ = mean CPUE)	28.5%	-0.14%	246	0.33	0.41
Base Case (3) including the daily file	26.7%	-0.34%	249		
Base Case (3) excluding the nozzle term	32.4%	-0.26%	278		
Base Case (3) with finer latitudinal scale	28.6%	-0.32%	286		

These results indicate very little difference in the slopes for the various models tested, except perhaps when δ is assumed to be 10% of the mean CPUE. However, an examination of the skewness and kurtosis for this model indicates that the residuals are not as close to normally distributed as in the case of assuming δ to be 50% of the mean CPUE. Furthermore, the amount of variation explained by this model is less than that of base case (3). The model excluding the nozzle term resulted in an r^2 greater than those for the other models shown in Table 12. This is a result of the analyses being conducted on a larger dataset (since the 12% of data lost through the merging process is retained for this sensitivity test).

The implications of all the results obtained from the GLM analyses are discussed in detail in Chapter 13.

CHAPTER 8 - THE BYCATCH DEBATE FOR THE WEST COAST

8.1 An inadequate adjustment for bycatch CPUE

The inclusion of the declared bycatch CPUE as an explanatory variable in the model is to account for the impact that targeting bycatch would have on the hake CPUE. Anon (1996a) developed a relationship between the CPUE of the species being modelled and bycatch, which could be used in GLMs to adjust for targeting bycatch species when only the total effort expended (on the species under consideration and on bycatch) is known. This relationship is derived in Appendix C.

In these circumstances it would be expected that as bycatch CPUE increases so hake CPUE decreases. The Industry consultants, however, made the important observation that, for the West Coast hake database, at low levels of bycatch CPUE a positive correlation exists between hake and bycatch CPUE, while the expected negative correlation is evident only at higher levels of bycatch CPUE (Bergh and Barkai, 1996b). This relationship is shown in Figure 7a. Given that this positive correlation is strong in the database used for the analyses, use of bycatch CPUE as an explanatory variable in the GLM would not properly be able to adjust for targeting on bycatch. This was highlighted by the consultants' argument that the magnitude of the slope of the bycatch parameter estimated in such a GLM was only a very small negative number indicating, counter intuitively, that very little hake CPUE had to be forfeited in order to increase bycatch CPUE (Bergh and Barkai, 1996b).

The shape of the plot in Figure 7a suggests a quadratic rather than a linear dependence. However, one cannot simply standardise hake CPUE by modelling bycatch CPUE as a quadratic function. The reason for this is that the purpose of the standardisation procedure is to correct the data to obtain an index for hake abundance. The positive correlation between hake and bycatch CPUE likely arises from the fact that there are periods of high and low catchability related to environmental conditions which would affect both hake and bycatch CPUE in the same direction. Adjusting for bycatch CPUE in the GLM in such circumstances would lead to an incorrect downward adjustment of the hake abundance index. However, adjustments are required to remove the bias caused by the lack of specifying effort targeting away from hake in favour of bycatch (causing the negative correlation). The problem here is that both effects are present, and it was therefore necessary to attempt to disentangle the two; hence the iterative procedure adopted in Section 8.3.

It may be argued that the positive portion of the curve in Figure 7a is already accounted for by the temporal and spatial effects included in the model. Figure 7b therefore indicates the relationship between hake CPUE after correcting for temporal and spatial effects, i.e. *ln*(hake CPUE+δ)-β_{year}-ω_{seas}-η_{depth}-τ_{lat}-λ_{vess}-*year*depth-year*season-depth*season*, and bycatch CPUE (corrected for vessel effects). This Figure illustrates that the positive correlation is still present, and hence that the iterative procedure to attempt to remove this effect still needs to be applied.

8.2 Possible solutions proposed by Industry consultants

One solution offered by the Industry consultants (Bergh and Barkai, 1996b) was to limit analyses to those days on which the percentage of hake caught was larger than some threshold, e.g. 80%. The rationale behind this was that by only considering those records in the database which were predominantly hake-directed, there would be no need to correct the hake CPUE for times when the percentage of hake was low due to deliberate and systematic targeting on bycatch (Bergh and Barkai, 1996b).

Another solution proposed by the consultants was to use the percentage of hake as an explanatory variable in the analyses since it represents a measure of bycatch targeting (Bergh and Barkai, 1996b).

Both of these methods proposed were considered to be flawed.

Anon (1996b) reports an example demonstrating that the first method proposed by the Industry consultants is problematic. Given low levels of targeting bycatch species, the resulting estimated average hake CPUE would be upwardly biased because the percentage criterion proposed would exclude some of the lower tail of the hake CPUE distribution from the analyses. This would not pose a problem if there was no change in the extent of targeting on bycatch species over time. However, if targeting on bycatch species had increased but hake abundance had not changed, even more of the lower tail of the hake CPUE distribution would be excluded from analyses as a result of failing to meet the threshold criterion. This would result in more recent hake CPUE estimates which were still further upwardly biased, indicating that the hake resource had increased, when in reality it had remained at the same level of abundance.

Punt *et al.* (1996) clearly illustrate that using the percentage of bycatch (or alternatively the percentage of target catch) as an explanatory variable can yield misleading results if the size of the population of interest exhibits a trend over time.

An alternative method of correcting for this positive correlation indicated between hake and bycatch CPUE at low levels of bycatch CPUE was therefore developed and investigated.

8.3 An alternative solution

A first attempt to correct for the positive correlation was to pool the observations over periods longer than a day as used in the current analysis (e.g. on a month basis, a trip basis, a season basis), to attempt to average over times with different catchabilities and therefore decrease the effect. Although promising, and displaying the expected reduction in the positive correlation effect, the problem with this approach was that depth and latitude factors (other important covariates in the GLM) often varied markedly over such longer periods. This precluded further development along these lines.

A method of adjusting the bycatch CPUE to attempt to remove the positive correlation shown in Figure 7a was therefore explored. This method assumes that the residuals associated with the bycatch CPUE (as an index of abundance of bycatch species) are correlated with those of the hake CPUE (as an index of abundance of hake) with correlation coefficient ρ. The bycatch CPUE can thus be adjusted by the following equation :

$$CPUE_i^{o*} = CPUE_i^o * e^{-vessel-nozzle} * e^{-\rho * \epsilon_i} \tag{9}$$

where $CPUE_i^{o*}$ is the corrected bycatch CPUE for a specific vessel-day combination i,
$CPUE_i^o$ is the recorded bycatch CPUE for vessel-day i,
$e^{-vessel-nozzle}$ is a correction term for the vessel effects, where *vessel* and *nozzle* are the vessel and kort nozzle effects as estimated in the GLM fit to ln(CPUE+δ) for base case (3) of Chapter 7,
ϵ_i is the residual of the GLM fit to ln(hake CPUE + δ) for vessel-day i, and
ρ is the correlation assumed.

The correlation is assumed to be a manifestation of related fluctuations in catchability. Values of 0, 0.25, 0.5, 0.75 and 1.0 were investigated, i.e scenarios ranging from zero correlation to perfect correlation between the log(hake CPUE) and log(bycatch CPUE) residuals.

The reason for adjusting by the vessel factors (*vessel* and *nozzle*) is to standardise effort similarly for both the hake and the bycatch CPUE. This is in the spirit of the model underlying the expected linearity of the log(hake CPUE) vs bycatch CPUE relationship (Appendix C).

In order to implement this bycatch adjustment, an iterative procedure was applied as follows.

1) Run base case (3) and retain the residuals.
2) Adjust the bycatch CPUE by applying equation 9, assuming a given value for ρ.
3) Rerun base case (3), replacing the bycatch CPUE with that which was calculated in 2), and retain the residuals.
4) Repeat 2) - 3) until (hopefully) convergence is obtained. Stability of the r^2 value or the bycatch CPUE parameter estimate obtained from the model may be used to indicate when convergence has been achieved.

An assumption underlying this iterative procedure is that there is no annual trend in the bycatch relative abundance (Appendix C). Here, nothing much is known about the trends in abundance for the bycatch species considered, except for that of squid and kingklip, both of which indicate a decrease in abundance.

8.4 Simulation testing

The appropriateness of correcting the bycatch CPUE in the above-mentioned manner was tested by simulation. Initially the following assumptions were made to generate the simulated data.

1) Hake biomass increases at a rate of 3% per annum. This relationship is reflected by:

$$B_{hake(y)} = 1 * e^{0.03y} \tag{10}$$

2) Bycatch species biomass = 1 for all years y.
3) Catchability coefficient for hake (q_{hake}) is 1.
4) Catchability coefficient for bycatch species (q_{byc}) is 0.5.
5) Of a total effort E = 1 applied by each vessel each day, the fraction exerted on hake is:

$$E_{hake} = [0.9 - \omega*y] + \acute{\eta} \tag{11}$$

where ω = 0.04, $\acute{\eta}$ from U[-0.05, 0.05] where U[a,b] is a uniform distribution on the interval [a,b], and y = 1 ... 5.

6) The fraction of effort exerted on bycatch species,

$$E_{byc} = 1 - E_{hake} \tag{12}$$

7) Hake catch on vessel-day i, $C_{hake} = q_{hake} * B_{hake} * E_{hake} * e^{\epsilon_i}$ **(13)**

where ϵ_i from $N(0, 0.1^2)$.

8) Bycatch catch on vessel-day i, $C_{byc} = q_{byc} * B_{byc} * E_{byc} * e^{\xi_i}$ **(14)**

where

$$\xi_i = \rho * \epsilon_i + \sqrt{(1-\rho^2)} * \phi_i \tag{15}$$

and ϕ_i from $N(0, 0.1^2)$, i.e. the log-residuals have a correlation coefficient of ρ with those for the hake catch.

9) The observed hake CPUE is given by C_{hake}/total effort $= C_{hake}/E = C_{hake}/1 = C_{hake}$ **(16)**

10) The observed bycatch CPUE is given by $C_{byc}/E = C_{byc}$. **(17)**

For a given **true** value of ρ, 5 years of hake CPUE and bycatch CPUE values were generated for 100 vessel-days each year (i.e. there are 500 data pairs for time period considered).

This is a very simplified approach, with the choice of a number of the parameter values being intended to capture the main qualitative features of the West Coast hake database, where the debate centres on increase rates for hake abundance in the range of 1% or perhaps 2% per annum over a 17 year period (this is roughly equivalent to increase rates of 3% or 6% per annum over a 5 year period as considered in this simulation exercise). Similarly, the choice of the value for ω reflects an approximate doubling of the extent of bycatch direction of effort over the full period, along the lines suggested by the real data. The primary concern of this exercise was to assess possible bias arising from the proposed adjustment procedure of equation 9 rather than to investigate precision-related aspects.

The iterative procedure to adjust the bycatch CPUE described in Section 8.3 was then applied to the simulated data. Note that in this simulation exercise there was no need to adjust for vessel effects (or spatial or seasonal effects) which were not included in the data generation process, under the assumption that appropriate adjustment for these effects would have already been achieved by the GLM. The simulation testing was intended to concentrate on the essence of the problem at hand, which is how successfully the effects of increasing hake biomass and increasing targeting on other species can be separated by the analysis.

The GLM applied to the simulated data can be expressed by the following equation (the δ adjustment being ignored here for the sake of simplicity):

$$ln(hake\ CPUE) = \alpha + \beta(year) + \gamma(bycatch\ CPUE) \quad \textbf{(18)}$$

where α is the intercept,

β is the year trend parameter, and

γ is the bycatch CPUE parameter.

For assumed values of ρ, the iterative procedure was applied to determine how well α, β and γ are estimated. The true ρ is known, and the purpose was to establish how well various assumed values for ρ yielded correct values assumed for α, β and γ, i.e. $\alpha = 0$, $\beta = 0.03$ and $\gamma = -2$ (which follows from the $q_{hake}/q_{bycatch}$ ratio in Appendix C). This procedure was run for true $\rho = 0, 0.25, 0.50, 0.75$ and 1.0 respectively. Seven iterations were computed for each value of ρ, with convergence being achieved in most cases before the last iteration.

Equation 18 is equivalent to the last equation in Appendix C given that the assumption $ln(x+1) \approx x$ holds. This approximation is only valid if $x \ll 1$. In this simulation exercise this approximation appears to hold since, on average, $CPUE_o = q_o B_o E_o = (1-E_h)/2$, so that $0.07 \leq CPUE_o \leq 0.15$.

8.5 Results from the simulation exercise

Various statistics of interest are shown in Tables 13 and 14 which indicate how well the method performed with respect to reflecting the true status of the resource. The main statistics quoted are the r^2, the year parameter estimate (β), and the bycatch CPUE parameter estimate (γ). Table 13 gives the results for assuming a 3% per annum increase in hake biomass, while Table 14 gives the results for assuming a 6% per annum increase (i.e. true $\beta = 0.06$).

TABLE 13 : r^2, β and γ values derived from the iterative procedure to correct for the positive correlation evident between hake and bycatch CPUE at low levels of bycatch CPUE in a simulated dataset. The model underlying the simulation has hake biomass increasing by 3% per annum over a 5 year period.

(i) r^2 (%)

		TRUE ρ				
		0	0.25	0.50	0.75	1.0
ASSUMED ρ	0	13.5	8.5	6.7	8.4	14.9
	0.25	21.5	13.9	8.8	6.7	8.8
	0.50	30.6	21.8	14.5	9.2	6.7
	0.75	39.5	30.6	22.5	15.4	9.3
	1.0	47.8	39.3	31.2	23.6	16.0

(ii) β (true β = 0.03)

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.01	-0.05	-0.02	-0.03	-0.05
	0.25	0.02	0.01	-0.00	-0.02	-0.04
	0.5	0.035	0.02	0.01	-0.00	-0.02
	0.75	0.05	0.04	0.03	0.02	0.002
	1.0	0.06	0.05	0.04	0.035	0.02

(iii) γ (true γ = -2.0)

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	-1.43	-0.73	-0.02	0.73	1.60
	0.25	-2.13	-1.49	-0.82	-0.08	0.83
	0.5	-2.77	-2.22	-1.62	-0.94	-0.05
	0.75	-3.37	-2.91	-2.41	-1.83	-1.04
	1.0	-3.91	-3.57	-3.19	-2.74	-2.14

TABLE 14 : r^2, β and γ values derived from the iterative procedure to correct for the positive correlation observed between hake and bycatch CPUE at low levels of bycatch CPUE in a simulated dataset. The model underlying the simulation has hake biomass increasing by 6% per annum over a 5 year period.

(i) r^2(%)

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	9.4	4.1	2.2	4.1	10.9
	0.25	17.8	9.8	4.5	2.3	4.5
	0.5	27.3	18.1	10.5	4.9	2.3
	0.75	36.6	27.3	18.8	11.4	5.1
	1.0	45.3	36.4	27.9	20.0	12.0

(ii) β values (true β = 0.06)

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.04	0.03	0.01	-0.0	-0.02
	0.25	0.05	0.04	0.03	0.01	-0.01
	0.5	0.06	0.05	0.04	0.03	0.01
	0.75	0.08	0.07	0.06	0.05	0.03
	1.0	0.09	0.08	0.07	0.065	0.05

(iii) γ (true γ= -2.0)

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	-1.43	-0.73	-0.02	0.73	1.60
	0.25	-2.13	-1.49	-0.82	-0.08	0.83
	0.5	-2.77	-2.22	-1.62	-0.94	-0.05
	0.75	-3.37	-2.91	-2.41	-1.83	-1.04
	1.0	-3.91	-3.57	-3.19	-2.74	-2.14

If this estimation method was unbiased, the diagonal in each of these Tables would present a result closest to the true situation, but it is evident from these results that this is not the case. The magnitudes of the estimated β and γ are nearly always both too small in such circumstances. Here, unbiased estimates require the assumption of a value of ρ greater than the true value. Furthermore, r^2 is always highest for the largest assumed value of ρ, whatever the true value. Thus the highest value of r^2 as the assumed ρ is varied is not indicative of a corresponding unbiased estimate of ρ.

8.6 Applying the correction method to base case (3)

The iterative procedure for adjusting the bycatch CPUE was applied to base case (3)[4]. Results were computed for values of assumed ρ of 0, 0.25, 0.5, 0.75 and 1.0. Only three iterations were performed in each case because of the time-consuming nature of this task. The results from this exercise are presented in Table 15 and are intended to be illustrative only. They would have had to be carried to convergence only if this correction method had been accepted by all INSEF participants.

[4]At the stage that these computations were performed, a slight modification had been made to data being utilised by base case (3). The 1993 data had been updated, and the midpoint of the grid block, rather than the northwest corner was used in the analysis (this essentially means that a value of 17 minutes was added to the latitude and longitude co-ordinates, where the minutes are recorded as decimalised minutes). The reason for using the mid-point of the grid block rather than the northwest corner is that drags would be allocated more accurately to a block in the accumulation process than would be the case if the northwest corner was used (R. Leslie, SFRI, pers. comm.).

As a result of the 1993 data being updated, the identification of potential coding errors had to be updated. The 99% quantile for effort was calculated to be 890 minutes (as was the case before), and the 99% quantiles for hake and bycatch CPUE in 1993 were 129.53 and 51.57 kg/minute respectively. Obviously the 99% quantiles for hake and bycatch CPUE for the other years (Table 6) did not change since it was only the 1993 data that had been updated. Given the updated information, n = 98092, p = 245.

TABLE 15 : Results obtained from adjusting the bycatch CPUE iteratively by use of equation 9 for the West Coast hake base case (3) GLM analysis. Only three iterations were completed due to the time-consuming nature of the iterative procedure. These results are illustrative only, to indicate the likely extent of the slope adjustment.

ρ	Iteration	r^2	Bycatch CPUE parameter estimate (γ)	Slope
0	Base Case (3)	28.38%*	-0.0087	0.0025%*
0.25	Base Case (3)	28.38%	-0.0087	
	Iteration 1	29.38%	-0.013	
	Iteration 2	29.40%	-0.014	
	Iteration 3	29.39%	-0.014	0.28%
0.5	Base Case (3)	28.38%	-0.0087	
	Iteration 1	30.88%	-0.018	
	Iteration 2	31.03%	-0.022	
	Iteration 3	30.99%	-0.022	0.58%
0.75	Base Case (3)	28.38%	-0.0087	
	Iteration 1	32.64%	-0.022	
	Iteration 2	33.22%	-0.032	
	Iteration 3	33.06%	-0.030	0.88%
1.0	Base Case (3)	28.38%	-0.0087	
	Iteration 1	34.46%	-0.024	
	Iteration 2	35.82%	-0.042	
	Iteration 3	35.05%	-0.036	1.12%

* The r^2 and slope statistics vary from those of base case (3) reported in Table 11 as a result of updating the 1993 data and using the mid-point of the latitude band in the analyses (see footnote 4 on previous page).

From Table 15 it is evident that the slope of the standardised hake CPUE becomes steeper as the value for ρ is increased. ρ=1 produces the best model fit in terms of the amount of variation explained (but simulation results from the previous Section indicated that this is not a reliable basis upon which to select the most appropriate values of ρ for unbiased results). The bycatch CPUE parameter estimate is larger and the slope of the standardised hake CPUE is greater for

$\rho=1$ than for other ρ values. Convergence is also almost always attained for each of the ρ values considered.

Figures 8a-e show vessel-factor-corrected observed *ln*(hake CPUE+δ) average values plotted against the 5 percentile points for the corrected bycatch CPUE distribution for $\rho = 0$ and for each of the last iterations in Table 15. It can be seen from these plots that the initial positive correlation is less marked for non-zero ρ. The point for lowest bycatch CPUE aside, the plot changes from negative to positive curvature as ρ increases. While it may be tempting to suggest the case nearest to linear ($\rho = 0.5$) as the one to be preferred as it is closest to the linearity assumed by the GLM model applied, it must be remembered that the method used does not adjust for other important covariates (season, depth, latitude) so that these plots may give a distorted picture of the underlying relationship.

The iterative correction procedure was also applied to a variant of the base case (3) where the dependence on bycatch CPUE was treated as quadratic rather than linear (henceforth referred to as base case (4)). The linear relationship derived between hake and bycatch CPUE in Appendix C is only an approximation, and allowing for quadratic dependence provides greater flexibility, and hence hopefully a less biased estimation procedure. Furthermore, preliminary investigations of the data indicated that the relationship between hake and bycatch CPUE was not strictly linear. Results for $\rho = 0$, 0.5 and 1.0 are shown in Table 16. The slope of the standardised CPUE for base case (3) and $\rho = 0.5$ are similar to their counterparts in Table 15, whereas the slope for $\rho = 1.0$ is lower when treating bycatch CPUE dependence as a quadratic function.

TABLE 16 : Results obtained from adjusting the bycatch CPUE iteratively in the base case (4) GLM analysis [where bycatch CPUE dependence is assumed to follow a quadratic function i.e. $ln(\mathrm{CPUE}+\delta)=\alpha+\beta_{year}+\omega_{season}+\eta_{depth}+\tau_{lat}+\lambda_{vessel}+\upsilon_{nozzle}+\gamma(Bycatch\ CPUE)+\gamma'(Bycatch\ CPUE)^2+\mathrm{interactions}+\epsilon$]. p = 246.

ρ	Iteration	r^2	(Bycatch CPUE) and (Bycatch CPUE)^2 parameter estimates (γ and γ')	Slope
0	Base Case (4)	28.51%	γ : 0.0000607 γ' : -0.00033	0.019%
0.5	Base Case (4)	28.51%	γ : 0.0000607 γ' : -0.00033	
	Iteration 1	31.27%	γ : -0.029 γ' : 0.00031	
	Iteration 2	31.19%	γ : -0.0311 γ' : 0.00032	
	Iteration 3	31.19%	γ : -0.0306 γ' : 0.00031	0.55%
1.0	Base Case (4)	28.51%	γ : 0.0000607 γ' : -0.00033	
	Iteration 1	36.44%	γ : -0.0474 γ' : 0.00060	
	Iteration 2	35.54%	γ : -0.0463 γ' : 0.00031	
	Iteration 3	33.57%	γ : -0.0288 γ' : 0.000015	0.79%

The results from the simulation exercise (Tables 13 and 14) illustrate that the method cannot be unbiased in general, and in order to gauge the level of likely bias it is necessary to generate simulated data which more closely represent the actual situation. The results in Tables 15 and 16 are not implausible however, and therefore provide no basis to reject this method as currently the best available to adjust for the positive correlation evident between the hake and bycatch CPUE. It was therefore considered appropriate to refine the simulation procedure in order to generate data that are more closely related to reality so that the likely biases of the method could be evaluated. It was also agreed in January 1997 that in subsequent analyses bycatch CPUE dependence would be assumed to follow a quadratic form.

8.7 Refining the simulation testing

As discussed in Sections 8.5 and 8.6, in order to evaluate the likely biases inherent in the method proposed to adjust for the positive correlation evident between hake and bycatch CPUE at low levels of bycatch CPUE, it became necessary to generate data more closely related to reality for the simulation testing exercise. A number of changes were therefore made to the assumptions set out in Section 8.4. The new set of assumptions were as follows:

1) The period over which the data were generated was extended to 17 years, which corresponds with the time period under consideration in the GLM analyses. Hence, the relationship for hake biomass is expressed by:

$$B_{hake(y)} = 1 * e^{\text{increase}*y} \tag{19}$$

where $B_{hake(y)}$ refers to the hake biomass in year y,
"increase" refers to 1% or 2% respectively, and
y refers to year.

2) A small constant (δ) is added to each hake CPUE datum to allow for the occurrence of zero CPUE values.
3) Bycatch species biomass = 1.
4) Catchability coefficient for hake (q_{hake}) = 1.
5) Catchability coefficient for bycatch species (q_{byc}) = 0.5.
6) Of a total effort E = 1 applied by each vessel each day, the fraction of effort exerted on bycatch species is:

$$E_{byc} = [\, 0.1 + \acute{\omega} y]*x^{+} \tag{20}$$

and that on hake is:

$$E_{hake} = [1 - E_{byc}] \tag{21}$$

Note that $\acute{\omega}$=0.007 which reflects an approximate doubling of effort directed at bycatch over the full period considered, as seems compatible with the actual data. If E_{byc} is greater than 1, it is set to 0.95, and hence E_{hake} is set to 0.05. x^+ is drawn from a distribution derived from the actual bycatch CPUE in the accumulated West Coast database (the method of generating this distribution is detailed in Appendix B).

7) Hake catch, $C_{hake} = q_{hake} * B_{hake} * E_{hake} * e^{\epsilon_i}$ **(22)**

where ϵ_i from $N(0, \sigma^2)$.

8) Bycatch catch, $C_{byc} = q_{byc} * B_{byc} * E_{byc} * e^{\xi_i}$ **(23)**

where

$$\xi_i = \rho * \epsilon_i + \sqrt{(1-\rho^2)} * \phi_i \tag{24}$$

and ϕ_i from $N(0, \sigma^2)$, i.e. the log-residuals have a correlation coefficient of ρ with those for the hake catch.

9) The observed hake CPUE is given by C_{hake}/total effort $= C_{hake}/E = C_{hake}/1 = C_{hake}$ **(25)**

10) The observed bycatch CPUE is given by $C_{byc}/E = C_{byc}$. **(26)**

For various true values of ρ, 100 vessel-days of data were generated for each of the 17 years. Figures 9a - e indicate the shape of the data when plotting hake CPUE against bycatch CPUE for $\rho = 1$ and various assumptions for the values of σ in equations 22 and 24 above. From these a σ of 0.4 was selected for subsequent tests since that plot seemed to best reflect the situation in reality (see Figure 7a for the shape of the actual data).

The GLM used in this simulation testing exercise was revised as follows:

$$ln(hake\,CPUE + \delta) = \alpha + \beta(year) + \gamma\,(bycatch\ \ CPUE) + \gamma'\,(bycatchCPUE)^2 + \epsilon \qquad \textbf{(27)}$$

where α is the constant,

β is the year trend parameter,

γ and γ' are the bycatch CPUE parameters, where bycatch CPUE dependence is assumed to be a quadratic function, and

δ is the constant added to the hake CPUE to allow for the occurrence of zero CPUE. Options of δ that were investigated were 5%, 10%, 20% and 50% of the mean CPUE respectively.

The iterative procedure discussed in Section 8.3 was applied. Again no adjustment was made for vessel factors, which are not included in the associated data generation process.

Here, for assumed values for ρ, the iterative procedure was applied to determine how well β is estimated. The results (in the form of r^2 and β) apply to assumed biomass increases of 1% and 2% per annum (Tables 17 - 24). Although up to 85 iterations were performed, convergence was not obtained for some of the cases.

TABLE 17 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.01, δ = 0.05*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	62.28%	57.43%	52.96%	48.99%	45.93%
	0.25	72.22%	68.89%	65.68%	62.56%	61.14%
	0.50	Oscillates between 77.49% and 77.66%	Oscillates between 74.78% and 75.06%	Oscillates between 72.20% and 72.52%	Oscillates between 69.70% and 70.09%	No Convergence
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.011	0.010	0.010	0.009	0.009
	0.25	0.012	0.011	0.011	0.011	0.009
	0.50	0.012	0.012	0.012	0.011	No Convergence
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

TABLE 18 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.01, δ = 0.1*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	60.88%	56.01%	51.55%	47.59%	44.49%
	0.25	69.50%	65.97%	62.21%	59.52%	57.42%
	0.50	74.68%	71.88%	69.14%	Oscillates between 66.43% and 66.69%	Oscillates between 64.40% and 64.68%
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.010	0.009	0.009	0.008	0.008
	0.25	0.011	0.010	0.010	0.010	0.008
	0.50	0.011	0.011	0.011	0.010	0.010
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

TABLE 19 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.01, δ = 0.2*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	58.36%	53.46%	49.00%	45.03%	41.91%
	0.25	65.36%	61.58%	58.04%	54.74%	52.30%
	0.50	70.13%	67.02%	66.05%	61.17%	Oscillates between 59.22% and 59.31%
	0.75	No convergence	No convergence	No convergence	Oscillates between 65.59% and 65.71%	Oscillates between 63.50% and 63.79%
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.008	0.007	0.007	0.007	0.007
	0.25	0.009	0.009	0.008	0.008	0.007
	0.50	0.009	0.009	0.009	0.009	0.008
	0.75	No convergence	No convergence	No convergence	0.009	0.009
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

TABLE 20 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.01, δ = 0.5*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	53.17%	48.25%	43.83%	39.89%	36.77%
	0.25	57.88%	53.78%	50.01%	46.55%	43.81%
	0.50	61.64%	58.09%	54.77%	51.67%	49.34%
	0.75	64.68%	61.51%	58.52%	55.70%	Oscillates between 53.65% and 53.66%
	1.0	Oscillates between 67.18% and 67.19%	Oscillates between 64.25% and 64.32%	Oscillates between 61.56% and 61.57%	58.97%	Oscillates between 56.82% and 56.91%

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.006	0.006	0.005	0.005	0.005
	0.25	0.006	0.006	0.006	0.006	0.005
	0.50	0.007	0.006	0.006	0.006	0.006
	0.75	0.007	0.007	0.007	0.006	0.006
	1.0	0.007	0.007	0.007	0.007	0.006

TABLE 21 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.02, δ = 0.05*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	62.30%	57.45%	52.98%	49.00%	45.92%
	0.25	72.24%	68.93%	65.71%	62.58%	Oscillates between 61.17% and 61.18%
	0.50	Oscillates between 77.50% and 77.69%	Oscillates between 74.80% and 75.10%	Oscillates between 72.21% and 72.56%	Oscillates between 69.72% and 70.12%	No convergence
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.020	0.019	0.019	0.018	0.018
	0.25	0.021	0.021	0.020	0.020	0.018
	0.50	0.021	0.021	0.021	0.020	No convergence
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

TABLE 22 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.02, δ = 0.1*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	60.93%	56.07%	51.61%	47.63%	44.51%
	0.25	69.56%	66.04%	62.68%	59.49%	57.49%
	0.50	74.74%	71.95%	69.20%	Oscillates between 66.5% and 66.76%	Oscillates between 64.46% and 64.73%
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.018	0.018	0.017	0.017	0.017
	0.25	0.019	0.019	0.018	0.018	0.017
	0.50	0.020	0.020	0.019	0.019	0.018/0.019
	0.75	No convergence	No convergence	No convergence	No convergence	No convergence
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

TABLE 23 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.02, δ = 0.2*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	58.46%	53.57%	49.12%	45.14%	41.98%
	0.25	65.49%	61.72%	58.18%	54.88%	52.43%
	0.50	70.25%	67.16%	64.19%	61.30%	Oscillates between 59.35% and 59.45%
	0.75	Oscillates between 73.48% and 73.72%	No convergence	No convergence	Oscillates between 65.7% and 65.85%	Oscillates between 63.64% and 63.88%
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.016	0.015	0.015	0.015	0.014
	0.25	0.017	0.016	0.016	0.016	0.015
	0.50	0.017	0.017	0.017	0.016	0.016
	0.75	0.018	No convergence	No convergence	0.017	0.017
	1.0	No convergence	No convergence	No convergence	No convergence	No convergence

TABLE 24 : Estimates of i) r^2 and ii) β from applying the iterative correction procedure to 17 years of simulated data (100 data points in each year). True β = 0.02, δ = 0.5*mean hake CPUE.

(i) r^2

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	53.39%	48.50%	44.08%	40.13%	36.97%
	0.25	58.14%	54.05%	50.29%	46.83%	44.06%
	0.50	61.91%	58.38%	55.06%	51.96%	49.63%
	0.75	64.94%	61.80%	58.81%	56.00%	53.02%
	1.0	67.45%	Oscillates between 64.54% and 64.60%	Oscillates between 61.85% and 61.86%	59.27%	Oscillates between 57.09% and 57.18%

(ii) β

		TRUE ρ				
		0	0.25	0.5	0.75	1.0
ASSUMED ρ	0	0.012	0.012	0.011	0.011	0.011
	0.25	0.012	0.012	0.012	0.012	0.011
	0.50	0.013	0.013	0.012	0.012	0.012
	0.75	0.013	0.013	0.013	0.013	0.012
	1.0	0.013	0.013	0.013	0.013	0.013

Comparing the results across the various δ scenarios, it is evident that the two smaller δ values yield unbiased estimates of β (under both 1% and 2% per annum biomass increases), whereas the larger δ values lead to negatively biased estimates. The small values of δ also yield near identical estimates of β irrespective of the true and assumed values of ρ. Here again, as in Section 8.4, r^2 increases with assumed ρ irrespective of true ρ, so that this statistic cannot be used to estimate the true value of ρ on the basis of the highest r^2.

CHAPTER 9 - FURTHER DATABASE CONSIDERATIONS

At a late stage in the deliberations (July 1997) it was discovered that the algorithm developed to separate the database into the drag and daily tally files was invalid (Leslie, 1997b). This was a consequence of inconsistent reporting of catches during trips. On some days the skippers recorded catches on a daily basis, whereas on other days the catches were recorded on a drag basis. Because the catches were separated into the drag and daily file on a trip basis, it sometimes happened that daily tallies occurred in the drag file. These records were then erroneously deleted because they were thought to have been associated with net problems (total catch for the drag was zero, but positive effort was recorded). This was brought to the attention of the DWG, and it was agreed that there was no need to separate the data in drag and daily tally files before accumulating the data over a day. It followed that the database had to be re-accumulated, and subsequent analyses were conducted on the re-accumulated file. In the re-accumulation process, the manner of averaging the various quantities was refined (see Section 5.4 for details on the previous method of averaging).

9.1 Re-accumulating the demersal database

A distinction between the daily and drag method of reporting catches no longer applied so it was not possible to identify potential coding errors at the drag level before accumulation took place. The following criteria were therefore adopted for re-accumulating the database.

- If fishing took place in more than one Division within a day for a particular vessel, the data were allocated to the Division in which at least 2/3 of the drags took place. If a 2/3 majority was not achieved, the records were ignored.

- Different net mesh sizes (75mm, 85mm and 110mm) may have been used on a day. If this occurred, the net mesh size which was used on least 2/3 of the drags for any given vessel was allocated to that day. If there was no two thirds majority, the mesh size was recorded as missing. Two records in the entire database had a mesh size of zero recorded. In both cases, 110mm was used on all other trawls of the day. Therefore a mesh size of 110mm was assumed for those two records.

- The target species were broadly separated into two categories; hake (H) and other (O). The species that was targeted in at least 2/3 of the drags was the target species allocated to that day. If there was no 2/3 majority, the target species was recorded as missing.

- If no depth was recorded for a particular drag (i.e. depth = 0 or 999), it was assumed to be the average depth of the other drags on that day for that particular vessel.

- If fishing took place in two Divisions on one day, the average latitude and longitude pertains only to the latitude and longitude recorded for the dominant Division.

- Namibian and foreign vessels (vessel code ≥ 500) were excluded from the accumulated file.

Hence, for a particular vessel, the demersal database was re-accumulated over a day, summing over the catches and effort, averaging over depth, latitude and longitude, and including the Division, target species and net mesh size as determined by the decision criteria.

9.2 Identifying potential coding errors in the re-accumulated database

From the re-accumulated West Coast hake database, the 99% quantile for effort was calculated to be 1090 minutes. Any records (days) with effort greater than this were excluded from the analyses. The 99% quantiles for hake CPUE and bycatch CPUE within each year were determined, and the CPUE were constrained to these values (Table 25).

A number of records in the accumulated database had positive effort, but zero total catch (i.e. hake + all bycatch species) recorded. It was assumed that these records reflected an aborted drag for some reason or another, and they were therefore excluded from the analyses. Again, only those days on which hake was recorded as the target species were included in the analyses.

TABLE 25: Year-specific 99% quantiles for West Coast hake and bycatch CPUE data from the re-accumulated demersal database for which catches were no longer separated into drag and daily tally files.

Year	99% Quantile for hake CPUE (kg/min)	99% Quantile for bycatch CPUE (kg/min)
1978	54.29	20.52
1979	70.77	30.45
1980	58.09	20.98
1981	56.59	16.83
1982	70.44	12.54
1983	64.75	17.52
1984	81.59	20.81
1985	82.00	22.57
1986	98.37	25.42
1987	75.79	29.43
1988	91.56	47.72
1989	84.65	37.33
1990	113.58	43.58
1991	106.83	52.36
1992	93.98	47.88
1993	106.87	56.76
1994	156.63	31.05

CHAPTER 10 - APPLYING THE BYCATCH CORRECTION METHOD TO THE REVISED DATA

Given that the results from the simulation testing exercise were sensitive to the choice of δ, it was agreed by the DWG to assume δ to be 10% of mean hake CPUE in the analyses of the actual data (since the simulation exercise indicated results to be the least biased for small values of δ). The iterative method was applied for various ρ values until convergence was obtained (Table 26). The statistics reported are different from those reported for base case (4) in Table 16 because the data had changed following the re-accumulation of the database (detailed in Chapter 9). Here n = 136585 and p = 256.

Convergence was not obtained for the cases of ρ = 0.75 and 1.0 (Table 26) and perfect convergence was not obtained for ρ = 0.5 although the results for this scenario did not fluctuate as markedly as for the greater ρ values. A modified procedure was attempted to achieve convergence for the higher ρ values. This procedure was carried out for the ρ = 0.75 scenario in order to determine whether it achieved the desired effects.

10.1 A method attempted to achieve convergence for high ρ

The rationale behind the method proposed below is that it is possible that the true result might be reflected by the average over a number of simulations, and that convergence might occur if one started close to the true result. Hence the following procedure was applied.

The relationships between hake and bycatch CPUE suggested by the parameter estimates for bycatch CPUE and (bycatch CPUE)^2 covariates from each of the iterations for the ρ = 0.75 option were plotted (Figure 10) by applying the equation:

$$y = ax + bx^2 + c \tag{28}$$

where a is the bycatch CPUE parameter estimate,

b is the (bycatch CPUE)^2 parameter estimate,

c is a constant assumed to be zero, and

x is the bycatch CPUE.

The average of all the curves was determined (Figure 10) and the a and b values for the closest approximating parabola were calculated by means of a minimisation procedure.

The following model was then applied to the data:

$$ln(\text{CPUE}+\delta) - a^*(bycatch\ CPUE) - b^*(bycatch\ CPUE)^2 = \alpha + \beta_{year} + \omega_{season} + \eta_{depth} + \tau_{lat} + \lambda_{vessel} + \upsilon_{nozzle} + \text{interactions} \tag{29}$$

For the first iteration the original bycatch was used as input. The residuals were obtained, and then a correction was made to the bycatch by applying the equation

$$CPUE_i^{o*} = CPUE_i^{o} * e^{-vessel-nozzle} * e^{-\rho*\epsilon_i} \tag{30}$$

where $CPUE_i^{o*}$ is the corrected bycatch CPUE for vessel-day i,

$CPUE_i^{o}$ is the bycatch CPUE for vessel-day i,

$e^{-vessel-nozzle}$ is a correction term for the vessel effects,

ϵ_i is the residual of the GLM fit to ln(hake CPUE + δ) for vessel-day i, and

ρ is the correlation assumed.

This corrected bycatch was then used in the model of equation 29 (keeping a and b the same). Again, residuals were obtained and the bycatch corrected, continuing until convergence with respect to r^2 or the slope was obtained. Using the residuals from the last iteration, the corrected bycatch was then calculated and returned to the right hand side of the equation and the iterations were continued. However, the results in Table 26 indicate that convergence was not obtained using this procedure. Fixing a and b through iterations 11 - 17, the model oscillated between two points, and freeing the bycatch CPUE parameters in iterations 18 - 20 resulted again in widely fluctuating results. This method of attempting to force convergence was therefore not considered further.

TABLE 26 : Results from the iterative procedure applied to the West Coast hake base case (4) to correct for the positive correlation observed between the hake and bycatch CPUE. Various values of ρ are assumed and in each case δ = 10% of mean hake CPUE.

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)² parameter estimate, γ'
0	Base Case (4)	29.61%	-0.54%	-0.000428	-0.000502
0.25	Iteration 1	31.58%	-0.20%	-0.0342	0.000222
	Iteration 2	31.53%	-0.16%	-0.0358	0.000209
	Iteration 3	31.53%	-0.17%	-0.0358	0.000217
	Iteration 4	31.53%	-0.17%	-0.0357	0.00021
0.50	Iteration 1	35.63%	0.19%	-0.05526	0.00045
	Iteration 2	35.26%	0.37%	-0.06370	0.00044
	Iteration 3	35.02%	0.33%	-0.05108	0.000066
	Iteration 4	35.33%	0.38%	-0.05749	0.00020
	Iteration 5	35.25%	0.37%	-0.0563	0.00017
	Iteration 6	35.27%	0.39%	-0.05447	0.000069
	Iteration 7	35.51%	0.34%	-0.06810	0.000599
	Iteration 8	35.30%	0.37%	-0.06012	0.000329
	Iteration 9	35.15%	0.37%	-0.05297	0.0000568
	Iteration 10	35.53%	0.33%	-0.07023	0.000705
0.75	Iteration 1	40.41%	0.45%	-0.06472	0.000509
	Iteration 2	36.97%	0.60%	-0.05996	0.0000715
	Iteration 3	39.31%	0.61%	-0.06213	0.0000006
	Iteration 4	38.49%	0.68%	-0.07332	0.000234
	Iteration 5	29.48%	-0.82%	-0.002853	0.00000011
	Iteration 6	36.29%	0.25%	-0.027104	0.0000051
	Iteration 7	39.95%	0.76%	-0.07537	0.00019
	Iteration 8	36.78%	0.41%	-0.05408	0.000132
	Iteration 9	28.96%	-0.92%	-0.000000038	0
	Iteration 10	38.34%	0.32%	-0.04424	0.000201
	Iteration 11*	26.88%	0.23%	N/A	N/A
	Iteration 12*	26.85%	0.25%	N/A	N/A
	Iteration 13*	27.23%	0.14%	N/A	N/A
	Iteration 14*	26.86%	0.24%	N/A	N/A

TABLE 26 continued.

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)^2 parameter estimate, γ'
	Iteration 15*	27.23%	0.14%	N/A	N/A
	Iteration 16*	26.85%	0.24%	N/A	N/A
	Iteration 17*	27.23%	0.13%	N/A	N/A
	Iteration 18**	39.86%	0.65%	-0.07373	0.000456
0.75	Iteration 19**	31.34%	-0.49%	-0.01676	0.00000158
	Iteration 20**	38.85%	0.42%	-0.05357	0.000308
1.0	Iteration 1	44.55%	0.57%	-0.06085	0.000378
	Iteration 2	30.34%	-0.68%	-0.008276	0.000000533
	Iteration 3	38.94%	0.36%	-0.026722	0.0000022
	Iteration 4	43.42%	0.98%	-0.08416	0.0001681
	Iteration 5	28.96%	-0.92%	-0.00000465	0
	Iteration 6	40.74%	0.38%	-0.036502	0.0001094
	Iteration 7	28.98%	-0.91%	-0.0000323	0
	Iteration 8	41.28%	0.40%	-0.039999	0.0001416

* Applying the model $ln(\text{CPUE}+\delta) - a^*(bycatch\ CPUE) - b^*(bycatch\ CPUE)^2 = \alpha + \beta_{year} + \omega_{season} + \eta_{depth} + \tau_{lat} + \lambda_{vessel} + \upsilon_{nozzle}$ + interactions.

** Using the residuals from iteration 17 to calculate the corrected bycatch CPUE and apply the model $ln(\text{CPUE}+\delta) = \alpha + \beta_{year} + \omega_{season} + \eta_{depth} + \tau_{lat} + \lambda_{vessel} + \upsilon_{nozzle} + \gamma(bycatch\ CPUE^*) + \gamma'([bycatch\ CPUE^*]^2)$ + interactions, where ($bycatch\ CPUE^*$) is the corrected bycatch CPUE - see equation 9.

10.2 A modified base case

By September 1997 time was of the essence, and in order that the revised OMP could be developed before the management advice to be given during 1998 became due, and given all the GLM analyses that had been completed at that stage, a final model had to be agreed upon so that a standardised CPUE could be obtained and used as input into the OMP and associated testing. Furthermore, various other issues required attention, specifically with respect to modelling hake size categories and extending the GLM analyses to the South Coast, all of which needed to be completed as pre-requisites for the OMP deliberations.

A model assuming δ to be 10% of the mean hake CPUE, and a correlation coefficient of $\rho = 0.5$, was selected by the DWG to be the final model applied in the iterative GLM analyses. Although it remains a concern that the correction method fails for higher values of ρ, the assumption of $\rho = 0.5$ reflects a fairly high degree of correlation, and it could be argued that a value larger than 0.5 is probably unrealistically high. It was also agreed by the DWG that the nozzle factor would be excluded from the analyses since its inclusion as an explanatory variable contributed very little to the predictive power of the model. This meant that the data that were lost previously in the merging process between the datafile and the vessel characteristic file would be retained. Furthermore, to be consistent with a decision made about the data that would be used in the South Coast analyses, only vessels belonging to companies whose fishing extended beyond areas very close to the coast were considered in the analysis (see Section 12.1).

Once all the various constraints had been taken into account for the accumulated West Coast database, it was agreed by the DWG that only those vessels remaining in the database that contributed more than 0.1% to the total number of records would be considered in the analyses. This constraint resulted from "a general concern about the representativeness of data from a vessel which contributes a very small number of points, and the concern that it is more likely to contribute to outliers which may have abnormally high variance and lead to biases in the final results" - OLRAC. The number of observations included in this final dataset was thus 136702, and $p = 256$.

The final model then applied is defined by:

$$ln(\mathrm{CPUE}+\delta) = \alpha + \beta_{year} + \omega_{season} + \eta_{depth} + \tau_{lat} + \lambda_{vessel} + \gamma(bycatch\ CPUE) + \gamma'(bycatch\ CPUE)^2 + \text{interactions} \quad \mathbf{(31)}$$

and is referred to as base case (5).

Because the nozzle term is no longer included in the model as an explanatory variable, the bycatch adjustment was modified as follows:

$$CPUE_i^{o*} = CPUE_i^{o} * e^{-vessel} * e^{-\rho * \epsilon_i} \quad \mathbf{(32)}$$

where $CPUE_i^{o*}$ is the corrected bycatch CPUE for vessel-day i,

$CPUE_i^{o}$ is the bycatch CPUE for vessel day i,

$e^{-vessel}$ is a correction term for the vessel effect,

ϵ_i is the residual of the GLM fit to ln(hake CPUE + δ) for vessel-day i, and

ρ is the correlation assumed, i.e. 0.5.

The results from applying the iterative procedure for correcting for the positive correlation observed between hake and bycatch CPUE given the base case model in equation 31 are shown in Table 27. The method converges fairly quickly with respect to the slope statistic, moving from an initial downward trend in resource abundance of some 0.4% per annum (ignoring the correlation effect) to an increasing trend in resource abundance of about 0.6% per annum.

TABLE 27 : Results from the iterative procedure applied to correct for the positive correlation observed between the hake and bycatch CPUE for base case (5) (equation 31).

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)^2 parameter estimate, γ'
0	Base Case (5)	29.53%	-0.37%	0.000234	-0.000518
0.50	Iteration 1	35.51%	0.43%	-0.05466	0.000444
	Iteration 2	35.15%	0.62%	-0.06307	0.000426
	Iteration 3	34.91%	0.58%	-0.05037	0.000056
	Iteration 4	35.28%	0.61%	-0.06071	0.000340
	Iteration 5	34.91%	0.60%	-0.05083	0.000055
	Iteration 6	35.39%	0.58%	-0.06801	0.000639
	Iteration 7	34.74%	0.58%	-0.04861	0.000049

The standardised CPUE obtained from iteration 7 in Table 27 is shown in Figure 11.

CHAPTER 11 - THE LINER DEBATE

11.1 The rationale for modelling hake size categories

The nominal CPUE for the small hake category indicates a 1.6% decrease in abundance per annum over the period 1978 - 1994, while that of the medium plus large hake category indicates an annual 6.8% increase in abundance over the same period.

Although a minimum mesh size of 110mm was proclaimed in 1975 for the West Coast fishery, it has recently been admitted that at that time the Industry considered this an uneconomical option, and proceeded to make use of smaller mesh net liners. The use of these smaller meshes would have impacted the CPUE of the small hake, resulting in these fish being retained by the nets, whereas normally many of them would have escaped through the larger 110mm mesh. The introduction of the smaller meshes should not, however, have biased the CPUE of the medium and large hake (Bergh and Barkai, 1996b). Given this, Bergh and Barkai (1996b) argued that restricting the analyses to the medium and large hake size classes would provide a fairer reflection of the true status of the hake resource, since these size classes were not subject to the biases as a result of effective mesh size changes as were the small hake. The DWG agreed to conduct further GLM analyses disaggregated on this basis, although some reservations were expressed since the values of catches made for separate size categories reflects rough estimates by the skippers, and there are therefore concerns about the comparability of the size categories over time and between companies (Leslie *et al.*, 1998).

11.2 The models

The following two models were applied to the small and medium plus large size categories respectively:

$$ln(\mathrm{CPUE}_{small}+\delta) = \alpha + \beta_{year} + \omega_{season} + \eta_{depth} + \tau_{lat} + \lambda_{vessel} + \gamma(bycatch\ CPUE) + \gamma'(bycatch\ CPUE)^2 + \text{interactions} \quad \textbf{(33)}$$

$$ln(\mathrm{CPUE}_{med+lar}+\delta) = \alpha + \beta_{year} + \omega_{season} + \eta_{depth} + \tau_{lat} + \lambda_{vessel} + \gamma(bycatch\ CPUE) + \gamma'(bycatch\ CPUE)^2 + \text{interactions} \quad \textbf{(34)}$$

Note: to avoid clatter, the subscripts "small" and "med+lar" for the parameters of equations 33 and 34 respectively have been omitted.

It was initially believed that a similar relationship might exist between the catch rate of small and medium+large hake CPUE as does between total hake CPUE and bycatch CPUE, i.e. that at low levels of CPUE there would be a positive relationship between medium + large and small hake CPUE, after which there would be a negative correlation between the two, reflecting the effects of size-specific targeting. However, no obvious evidence for such a relationship was found. Figures 12 and 13 show the relationships between medium+large and small hake CPUE, both of which indicate a positive correlation only. The CPUE of "other sized hake" was therefore not included as an explanatory variable in these two models.

Because the positive correlation between bycatch CPUE and hake CPUE is still evident at low levels of bycatch CPUE for both small and medium+large hake categories, the iterative procedure to correct for the bycatch which is discussed at length in Chapter 8 was again applied. The same values of δ (10% of the mean hake CPUE) and ρ (0.5) as were used in the base case (5) analysis were used here. The results are shown in Tables 28 and 29 for the small and medium+large hake models respectively.

TABLE 28 : Results from the iterative procedure applied to correct for the positive correlation observed between West Coast hake and bycatch CPUE. The small hake category is the dependent variable (equation 33).

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)^2 parameter estimate, γ'
0	Base Case	21.85%	-4.85%	-0.01074	-0.000326
0.5	Iteration 1	32.13%	-3.61%	-0.08856	0.000904
	Iteration 2	23.90%	-4.74%	-0.02273	0.0000009
	Iteration 3	32.00%	-3.73%	-0.10250	0.001341
	Iteration 4	28.44%	-3.55%	-0.05968	0.0000026
	Iteration 5	32.45%	-3.55%	-0.13215	0.002450

TABLE 29 : Results from the iterative procedure applied to correct for the positive correlation observed between West Coast hake and bycatch CPUE. The medium + large hake category is the dependent variable (equation 34).

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)^2 parameter estimate, γ'
0	Base Case	38.19%	2.72%	0.02330	-0.000882
0.50	Iteration 1	41.41%	3.78%	-0.05202	0.000444
	Iteration 2	41.57%	4.06%	-0.06300	0.000415
	Iteration 3	41.07%	3.87%	-0.04679	0.0000285
	Iteration 4	41.51%	4.02%	-0.05718	0.000253
	Iteration 5	41.35%	4.00%	-0.05165	0.0000453
	Iteration 6	41.78%	4.02%	-0.07691	0.0009997

Figure 14 shows the standardised CPUE for both the small and medium+large size categories obtained from the final iteration for each model. This Figure indicates that CPUE for small hake has decreased considerably, while that of larger hake has been increasing over the time period considered. Figure 14 therefore suggests a change in selectivity-at-age in the hake fishery reflected in the decrease in CPUE of the smaller hake over the period 1985 - 1994. This is consistent with the advice that liners were in use early in the period, and may indicate that these were being phased out starting from about 1985, since prior to 1985 the small hake CPUE was fairly stable, after which it declined steadily.

CHAPTER 12 - GLM ANALYSES OF THE SOUTH COAST HAKE CPUE SERIES

Time constraints precluded an in-depth analysis of the South Coast CPUE data. It was therefore agreed by all parties in the DWG and hake INSEF group that the same procedure and model (slightly modified) as applied to the West Coast CPUE data also be applied to the South Coast data until a more detailed analysis of the South Coast could be undertaken.

12.1 Identifying potential coding errors

As with the West Coast, potential coding errors in the accumulated database for the South Coast needed to be identified and removed. Essentially the same criteria that were applied in the final West Coast GLM model were adopted for the South Coast.

Data available from companies operating only close inshore on the South Coast are considered to be of poorer quality than those available from the offshore companies (P. Simms, SFRI, pers. comm.). Because data from these companies form only a small proportion of the database (and their catches make up only a small proportion of total hake catches), they were excluded from the analyses for the South Coast resource.

Similarly to the West Coast analyses, potential coding errors were identified as days with effort values greater than the 99% quantile for effort (865 minutes), and any hake and bycatch CPUE values greater than the 99% quantiles, calculated on an annual basis (Table 30). Only those days on which hake was recorded as the target species were considered. A number of records (days) had zero total catch (hake catch + declared catch + undeclared catch) but positive effort recorded, and these were excluded from the analyses. Furthermore, any vessels which contributed to less than 0.1% of the total number of records in the database once potential coding errors had been removed were also excluded from the analyses (the rationale for this being given in Section 10.2). Exclusion of records following from the above censorships resulted in 21% of the data being excluded from the analyses ($n = 61532$ and $p = 186$).

TABLE 30 : Year-specific 99% quantiles for South Coast hake and bycatch CPUE data.

Year	99% Quantile for hake CPUE (kg/minute)	99% Quantile for bycatch CPUE (kg/minute)
1978	82.81	46.45
1979	78.50	60.57
1980	68.82	56.00
1981	50.17	44.03
1982	68.76	45.05
1983	59.00	62.90
1984	79.57	40.69
1985	75.26	51.90
1986	89.39	58.21
1987	75.23	61.73
1988	77.28	86.31
1989	76.99	154.67
1990	82.03	260.81
1991	121.87	175.29
1992	119.25	119.48
1993	97.70	112.65
1994	115.98	94.54

12.2 The base case

The positive correlation observed between bycatch and hake CPUE at low levels of bycatch CPUE on the South Coast (Figure 15) is not as marked as in the case of the West Coast, but it had been agreed by the DWG (in the interest of consistency) that the same analysis procedure as applied to the West Coast would be adopted for the South Coast. The models and values of ρ and δ may of course revised once a more detailed analysis of the South Coast CPUE data has been undertaken.

The base case model for the South Coast is expressed as follows:

$$ln(\text{CPUE}+\delta) = \alpha+\beta_{year}+\omega_{season}+\eta_{depth}+\tau_{long}+\lambda_{vess}+\gamma\,(bycatch\ CPUE)+\gamma'(bycatch\ CPUE)^2 + \text{interactions} \quad \textbf{(35)}$$

where α is the intercept,

year is a factor with 17 levels (1978 - 1994),

season is a factor with 4 levels (*summer*, *autumn*, *winter* and *spring* as for the West Coast),

long is a factor with 2 levels referring to longitude:
$<22^{\circ}00'$E and
$\geq 22^{\circ}00'$E,

depth is a factor with 3 levels (depth ranges 0-100m, 101-200m and > 200m),

vess is a factor with 114 levels (referring to each individual vessel),

bycatch CPUE is a continuous variable upon which *ln*(hake CPUE+δ) is assumed to depend quadratically, and

interactions refer to *year*depth*, *year*long* and *depth*long* interactions.

The standardised CPUE is calculated by taking only the depth ranges 100m and above into account because there are some years in which no fishing took place in depths less than 100m. An investigation of the database indicated that only 0.03% of the records indicated fishing at depths of less than 100m.

The following equation is thus applied to standardise the South Coast hake CPUE:

$$CPUE_{year} = \Sigma_{strata}[e^{(\alpha + \beta_{year} + \text{(average season)} + \text{depth} + \text{long} + \text{median vess estimate} + \gamma^*\text{(average bycatch CPUE)} + \gamma'^*\text{(average bycatch CPUE)}2 + \text{interactions})} - \delta] * A_{stratum}/A_{total} \quad \textbf{(36)}$$

where $A_{stratum}$ is the size of the stratum (e.g. depth 100-200m and longitude < 22^{O}), and

A_{total} is the total size of the area considered.

The area sizes for the longitude/depth combinations for the South Coast are shown in Table 31.

TABLE 31: The size of the area (nm^2) covered by longitude/depth combinations on the South Coast. The percentage contribution of each stratum to the total area is shown in brackets.

	Depth (m)			
Longitude (E)	0 - 50	51 - 100	101 - 200	201 - 500
< 22°	441.63 (1.53%)	3734.59 (12.90%)	7555.34 (26.10%)	1293.27 (4.47%)
≥ 22°	1051.58 (3.63%)	3861.35 (13.34%)	8469.5 (29.26%)	2534.82 (8.76%)

The results of applying the iterative bycatch correlation correction procedure (see Chapter 8) assuming δ = 10% of the mean hake CPUE and ρ = 0.5 are shown in Table 32.

TABLE 32 : Base case results obtained from the South Coast hake GLM analyses (equation 35) using the same method as applied to the West Coast CPUE data.

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)^2 parameter estimate, γ'
0	Base Case	31.20%	4.02%	-0.01148	0.000014
0.50	Iteration 1	40.66%	3.68%	-0.02951	0.000091
	Iteration 2	39.40%	3.61%	-0.03237	0.000066
	Iteration 3	39.68%	3.66%	-0.02876	0.000016
	Iteration 4	39.84%	3.58%	-0.03430	0.000101
	Iteration 5	39.15%	3.68%	-0.02719	0.000015
	Iteration 6	39.79%	3.64%	-0.03032	0.000027
	Iteration 7	39.81%	3.63%	-0.03091	0.000038

The standardised CPUE obtained from iteration 7 in Table 32 is shown in Figure 16.

12.3 Modelling the hake size categories

As for the West Coast, modelling the CPUE of the different size categories of hake on the South Coast was considered. As in that case, small hake were treated as a separate category, and medium and large hake were lumped together. The nominal CPUE for the small hake size category indicates a 1% increase in abundance per annum over the period 1978 - 1994, while that of the medium plus large hake category indicates a 5.6% increase per annum over the same period.

The following two models were fitted to the respective size categories:

$$ln(\text{CPUE}_{small}+\delta) = \alpha+\beta_{year}+\omega_{season}+\eta_{depth}+\tau_{long}+\lambda_{vessel}+\gamma(bycatch\ CPUE)+\gamma'(bycatch\ CPUE)^2+\text{interactions} \quad \textbf{(37)}$$

$$ln(\text{CPUE}_{med+lar}+\delta) = \alpha+\beta_{year}+\omega_{season}+\eta_{depth}+\tau_{long}+\lambda_{vessel}+\gamma(bycatch\ CPUE)+\gamma'(bycatch\ CPUE)^2+\text{interactions} \quad \textbf{(38)}$$

where the various factors have already been defined in equation 35. The results from the size category GLMs are shown in Tables 33 and 34 respectively.

TABLE 33 : Results from modelling the small hake size category for the South Coast.

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)² parameter estimate, γ'
0	Base Case	23.81%	1.22%	-0.01874	0.000065
0.5	Iteration 1	36.69%	1.07%	-0.03568	0.000079
	Iteration 2	23.96%	1.38%	-0.00725	0.00000003
	Iteration 3	35.62%	1.03%	-0.03526	0.0001002
	Iteration 4	34.40%	0.81%	-0.04108	0.0000433
	Iteration 5	32.67%	1.25%	-0.03059	0.00000004
	Iteration 6	35.74%	0.85%	-0.04254	0.0000714
	Iteration 7	21.73%	1.52%	-0.00018	0
	Iteration 8	34.03%	1.27%	-0.02651	0.0000485
	Iteration 9	24.16%	1.36%	-0.00720	0.00000043
	Iteration 10	31.84%	1.36%	-0.01905	0.00000055

TABLE 34 : Results from modelling the medium + large hake size category for the South Coast.

ρ	Model	r^2	Slope	Bycatch CPUE parameter estimate, γ	(Bycatch CPUE)^2 parameter estimate, γ'
0	Base Case	30.02%	5.43%	-0.00326	-0.000032
0.50	Iteration 1	37.57%	5.10%	-0.02489	0.000071
	Iteration 2	37.06%	5.02%	-0.02976	0.000063
	Iteration 3	37.16%	5.07%	-0.02591	0.000006
	Iteration 4	37.48%	4.92%	-0.03441	0.000136
	Iteration 5	37.27%	5.04%	-0.02955	0.000069
	Iteration 6	37.28%	5.04%	-0.02720	0.000007

The standardised CPUE series for the last iteration for each model are shown in Figures 17 - 18.

CHAPTER 13 - GENERAL DISCUSSION AND CONCLUSIONS

The standardisation of the hake CPUE has been a fairly lengthy process with much debate centring around the selection of a base case analysis for use in the assessment of the West Coast hake resource. Consequently, insufficient time was available for the DWG to consider a more in-depth analysis of the South Coast CPUE time series, but this is earmarked for the future.

Three factors can be identified as primary contributors to the extended debate for the West Coast resource:

1) the inclusion of bycatch CPUE as an explanatory variable in the GLM was unable to adjust adequately for targeting other species,
2) extensive early use of liners (subsequently phased out) would have biased the CPUE as an index of abundance, and
3) the Industry had difficulty in accepting that hake abundance on the West Coast had not increased as fast as they believed to be the case.

The first of these factors (the bycatch issue) was addressed by adopting an iterative procedure for adjusting the bycatch CPUE, assuming that the residuals associated with the bycatch CPUE as an index of abundance were correlated with those of the hake CPUE with a correlation coefficient ρ. Initially a range of ρ values was investigated, and a value of 0.5 was eventually accepted for analysis purposes. This procedure was tested by simulation and considered to be the most appropriate method available to date to address the otherwise inadequate adjustment of the GLM for targeting on bycatch species. Prior to correcting for the inadequate adjustment for bycatch CPUE, the results indicated that the West Coast hake resource was declining, whereas once the correction had been made, the results indicated that the resource was increasing, although not as fast as the rate that had been estimated by the old "power factor" approach prior to these analyses.

The second of these factors (the liner issue) was addressed by performing GLM analyses by hake size category rather than lumping all hake together. It was argued that the CPUE of the small hake would have been biased as an index of abundance by the use of liners whereas that of medium + large hake would not (Bergh and Barkai, 1996b). Therefore separate GLM analyses were conducted for these two "size" classes respectively. It was argued that the medium + large hake category, after GLM standardisation, better reflected resource abundance trends. The results indicated that abundance of small hake had apparently declined substantially over the period of the study, while that of the medium+large hake had increased substantially - mutually incompatible inferences unless there had been a change of selectivity (possibly through a decline in the use of net liners) over the period. This then implied that the inclusion of small hake was notably biasing the results of the GLM applied to hake of all sizes combined. Concern was raised about the comparability of size categories over time and between companies (Leslie *et al.*, 1998), but the Industry argue confidently that, at the broad level of aggregation into size classes as used here, there is no need for concern.

Another method of determining the effect of the use of liners is for Industry to provide a date from which they were fairly confident that extensive use of liners was no longer common practice. This would allow for the comparison of results (where they overlap) for the base case as it stands, and for a GLM which takes account of data only over the period for which liners were not being used. The Industry, however, have thus far only been able to advise a range of dates over which the use of liners was being phased out (see sub-Section 5.6.1).

The third topic that led to much debate of the West Coast analysis was the fact that the standardised CPUE (at least prior to modelling separate size classes) indicated that hake abundance had not increased as much as the Industry had expected. Base case (5) indicated a slight upward trend in abundance of 0.6% per annum, inconsistent with the Industry's perception that there had been a substantial improvement in the resource over the 17 year period considered in the study (as suggested, for example, by the nominal CPUE increase of some 4% per annum). The difference between the extent of resource recovery as indicated by base case (5) and the perceptions of the Industry can be attributed mainly to three factors:

i) there has been an increase in the effective average fishing power of the vessels in the fleet,

ii) vessels have moved to fishing in deeper waters where catch rates tend to be higher, and

iii) although there has been an increase in fish density in deeper waters over time, this is more than offset by a simultaneous decrease in fish density in shallower waters.

Only the first of these factors was taken into account (albeit roughly) in previous analyses of hake catch rate data, when the power factors which were crudely calculated many years ago were applied to standardise the effort. These decreased the estimated annual rate of increase from 3.8% to 1.7%, but the plot in Figure 19 indicates that the extent of this correction was still too small. In this Figure the effective average power of the vessels (normalised to 1978) is plotted over time by applying the equation:

$$P_y = \frac{\sum_v (f_v E_{v,y})}{\sum_v E_{v,y}} \qquad \textbf{(39)}$$

where P_y is the effective average power of the vessels in the fleet in year y,

$f_v = e^v$, where v are the vessel factor estimates for base case (5) (denoted by the "new" series in Figure 19), or alternatively f_v = the old power factors in the case of no GLM standardisation having been performed (denoted by the "old" series in Figure 19), and

$E_{v,y}$ is the nominal fishing effort expended in year y by vessel v.

The influence of factors ii) and iii) can be understood from inspection of Figures 20 and 6. In Figure 20, hake density is plotted as a function of depth for four successive sub-periods, each of a few years duration. There is a trend of increasing density with depth for all of these sub-periods, but as time progressed, although hake density in deeper waters increased, the density in shallow waters (0 - 300m) fell. The latter more than offsets the former when the relative areas of the strata concerned are taken into account. Figure 6 indicates that the average depth of trawls made each year has increased over time. Taken together, the two depth effects contribute to a trend in nominal catch rate which is greater than that in the actual resource abundance.

Figure 21 considers only the 200 - 500m depth range, for which results are considered to be most reliable, and plots the estimated proportion of abundance to be found in the first 100m of this range (i.e. 200 - 300m) as a function of time. This proportion has fallen from 0.49 in 1978 to 0.34 in 1994, thus confirming the movement of the fleet towards deeper waters over time.

Not only were the standardised CPUE results inconsistent with Industry perceptions, but they also seemed inconsistent with the trends shown by independent research surveys of the hake resource abundance. Figure 22 shows the results of the winter survey series (now discontinued), and Figure 23 shows the summer survey series results. Both Figures show results for the full depth range and for depths exceeding 200m. The summer series for the full depth range indicates an increase in abundance of 6±5% (1 standard error) per annum, whereas that for depths exceeding 200m indicates an increase in abundance of 7±3% per annum. Comparing these figures to the GLM result of a 0.6±0.5% increase in abundance, a large difference is suggested (although the difference is (just) not significant at the 5% level). This discrepancy may be explained by examining the results of an age structured production model (one of the assessment methods being applied) which takes into account catch-at-age information from both the commercial catches and the surveys, as well as CPUE and survey biomass trends (Anon, 1997a, Geromont and Butterworth, 1997a). The commercial catch-at-age data suggest that fewer young fish are currently being caught than was the case in the late 1970s. The reasons for this are not totally clear, but likely contributory factors are that the fleet has moved to deeper waters over time (hake size tends to increase with depth) and that liners are no longer being used. The net effect is that the CPUE at present reflects a smaller component of the total biomass of the resource than was the case some 15 - 20 years ago. This explains how the total biomass of the resource, as indicated by the survey results, can have increased faster than the exploitable component of the biomass which is indexed by the CPUE (Anon, 1997a, Geromont and Butterworth, 1997a). The model fits obtained from the age-structured production model to the GLM standardised CPUE data and the summer survey series for the West Coast are shown in Figure 24.

CHAPTER 14 - FUTURE WORK

The GLM analyses for hake CPUE for both the West and South Coasts covered the period 1978 - 1994 because data were available for these years at the start of the project, and comparability across the various analyses was desired. It would, however, be desirable to produce a standardised CPUE series covering as many years of data as are available for input into the OMP. This therefore now requires that the 1995 and 1996 data also be included in the GLM analyses.

As a result of the limited time available for analysing the South Coast CPUE data, the model developed for the West Coast was used (with minor changes) to standardise the South Coast hake CPUE time series. However, it appears that not all the features of the West Coast data are reflected in those for the South Coast, and a more detailed examination of the latter data is therefore desirable. For example, the mesh size problem encountered on the West Coast is probably not as marked on the South Coast where the legal minimum mesh size is 75mm; the positive relationship evident between hake and bycatch CPUE at low levels of bycatch CPUE is less severe on the South Coast, so that the iterative procedure developed for the West Coast may not be required when analysing the South Coast data.

Attempts should be made to improve the method used to correct for the positive correlation evident between hake and bycatch CPUE at low levels of bycatch CPUE, because this method fails to converge when high values are assumed for the correlation coefficient, ρ.

Throughout the analyses it has been assumed that the CPUE data are log-normally distributed. Studies carried out in other international fora (e.g. ICCAT) have found that for some fisheries alternative error structure models are more appropriate, e.g. Poisson and gamma error models. Consideration should therefore also be given to these models in the South African hake context. In particular, the analyses conducted to date have assumed that the residuals obtained from the regression have constant variance, i.e. are homoscedastic. If heteroscedasticity (changing variance) is present, an appropriate weighting procedure should be applied to achieve minimum variance estimation. Figure 25 shows a plot of the standard deviation of the residuals for the base case (5) fit (see Section 10.2) against effort, which shows that the variance at low effort levels is higher than that at high effort levels. Since this plot is hyperbolic in shape, it may be fitted by ($\alpha+\beta$/effort) and the appropriate weighting applied in the regression would then be the inverse of this (Butterworth, 1996a). It may therefore be appropriate in future to iteratively re-weight in the hake GLM (as described later for the South Coast rock lobster analysis - see sub-Section 16.4.2).

SECTION B : THE APPLICATION OF GENERAL LINEAR MODELLING FOR DETERMINING TRENDS IN ROCK LOBSTER ABUNDANCE OFF SOUTH AFRICA

CHAPTER 15 - INTRODUCTION

The two most important commercially exploited rock lobster species off southern Africa are the West and South rock lobsters, *Jasus lalandii* and *Palinurus gilchristi* respectively. Although these fisheries make up a small percentage of the total mass of all commercial catches (Anon, 1997b), the wholesale value of the catches of these species is one of the highest across all fishing sectors (Anon, 1997b).

Various techniques have been used to assess the status of the South Coast rock lobster resource, none of which has to date been able to provide an entirely reliable assessment of the resource. In 1994 an age-aggregated surplus production model, which made use of a Bayesian estimation procedure to evaluate selected management quantities, was accepted for assessing the status of the resource (Geromont and Butterworth, 1995). The results of this method, however, were very sensitive to the prior distribution assumed for a recent harvest proportion (developed from tag-recapture data), and it was suggested that the application of an age-structured production model rather be attempted (Butterworth and Geromont, 1996a). An evaluation of such a model indicated that fits to the CPUE and catch-at-age data deteriorated as greater weight was assigned to the tag-recapture data, and this method was therefore not considered appropriate until a decision was made on the weight to apply to the tag-recapture data in the likelihood function, and a more efficient numerical integration technique was developed (Geromont and Butterworth, 1997b).

Given the problems associated with both the age-aggregated and age-disaggregated production models, a Bayesian replacement yield model was employed to obtain some indication of the likely recent level of the sustainable yield of the resource (Butterworth and Geromont, 1996b). Such a model, however, cannot make allowances for the possibility that higher sustainable yields may be available at lower levels of biomass (Anon, 1997c), and the results from this model can therefore only serve as a guideline for estimating appropriate TAC levels.

The results obtained from the surplus production model in 1994 indicated the biomass to be declining by approximately 2% per annum since the 1979/80 fishing season, and that the then

TAC of 477 tons was not sustainable in the long term (Anon, 1996c). The rock lobster working group (RLWG) therefore agreed in 1994 to reduce the TAC by 25 tons per annum until a sustainable level, believed then to be in the region of 400t, was reached. This approach has since continued to be applied in the absence of a reliable assessment, except in 1996, when it was recommended that the reduction in TAC be continued, but at a slower rate until greater certainty about sustainable yield levels could be obtained (Anon, 1996c). The TAC was consequently reduced by only 12 instead of 25 tons. In 1997 the final phase of this reduction approach was implemented, and a TAC of 402 tons was recommended (two tons being allocated for research purposes) (Anon, 1997c).

A size-based model which takes into account various sources of information (CPUE and catch-at-size data for both the commercial fishery and a recently instituted research survey, the sex composition of the catch and historic somatic growth data) has been employed to assess the status of the West Coast rock lobster resource (Johnston, 1996a; 1996b ; Johnston and Butterworth, 1995). Over time this model has been refined, and has recently been used as a basis to test an OMP (Johnston and Butterworth, 1996a; 1996b; 1997a; 1997b; 1997c; Johnston, 1996c). This OMP was implemented for the first time in 1997; the formula which it uses to compute the TAC depends on three indices: a commercial CPUE series, a fisheries independent CPUE series and somatic growth information (De Oliveira *et al.*, in press, Anon, 1997d). The TAC is adjusted upwards if these indices suggest an increase, or conversely, adjusted downwards if they indicate a decrease (De Oliveira *et al.*, in press).

Although different methods are used to assess the status of the two rock lobster resources, in both cases commercial CPUE data are essential inputs and the results obtained depend critically on the recent trends indicated by these data. The commercial CPUE data for *P. gilchristi* and *J. lalandii* have therefore been standardised by means of applying GLMs to attempt to remove bias introduced into estimates of trends by the non-random nature of commercial fishing as a sampling process.

CHAPTER 16 - THE SOUTH COAST ROCK LOBSTER RESOURCE

16.1 History of the fishery

P. gilchristi inhabit the rocky shelf areas between Cape Point and Port St. Johns (Cockroft *et al.*, 1995) and are caught in commercial quantities between the Agulhas Bank and East London (Figure 26). They occur at depths of between 55 - 360m (Holthuis, 1991) but are fished up to depths of 200m only. Commercial exploitation started in 1974 when traps set in deep water rocky areas off Port Elizabeth caught large amounts of lobster (Pollock and Augustyn, 1982). The fishing ground has historically been divided into four zones, namely the Agulhas Bank area, the Cape St Francis area, the Port Elizabeth area and the Port Alfred area (Figure 26). At the start of the fishery the fishing season was defined by a calender year, but since 1976 this season has started towards the end of one year and ended towards the middle or end of the following year (Stander, 1991). Presently fishing takes place year-round, with the season ending on 30 September and re-opening on 1 October.

In 1975 foreign vessels joined the *P. gilchristi* fishery and fishing effort increased rapidly (Pollock and Augustyn, 1982; Stander, 1991). These vessels withdrew from the fishery in 1976, prior to the implementation of a 200 nm exclusive economic zone on 1 November 1977. Effort increased up until 1977/78, but without a concomitant increase in catches (Pollock and Augustyn, 1982). Low yields encouraged vessels to withdraw from the fishery in 1979/80 and focus on yellow-fin tuna (*Thunnus albacares*) which were particularly abundant at the time (Pollock and Augustyn, 1982). The catch and unstandardised effort and CPUE series for the period 1977/78 - 1996/97 are shown in Table 35 (these data were derived directly from the South Coast rock lobster database - see Section 16.3). The TAC for each fishing season (van Zyl, 1996a) is also shown in Table 35.

TABLE 35 : The South Coast rock lobster catch, and unstandardised effort and CPUE data for the period 1977/78 - 1996/97. These data were derived directly from the South Coast rock lobster database (see Section 16.3). TAC source : van Zyl (1996a).

Season	TAC(t)	Catch (t)	Effort (# traps)	CPUE (kg/trap)
77/78		726.3	3461610	0.21
78/79		446.7	2212530	0.20
79/80		108.3	644080	0.17
80/81		166.3	695511	0.24
81/82		326.1	1529464	0.21
82/83		385.6	2078457	0.19
83/84		518.3	2687232	0.19
84/85*	450	158.6	1089897	0.15
85/86*	450	155.6	1042723	0.15
86/87*	450	127.7	689935	0.19
87/88*	452	133.5	633727	0.21
88/89*	452	178.9	933453	0.19
89/90*	452	174.5	816745	0.21
90/91*	477	186.6	1084460	0.17
91/92	477	465.1	2888558	0.16
92/93	477	470.7	2843750	0.17
93/94	477	497.1	3167118	0.16
94/95	452	461.4	3442043	0.13
95/96	427	435.2	3216586	0.14
96/97	415	413.8	3623376	0.11

* The catch and effort listed for these years does not correspond to the total catch and effort in each year. The Industry admitted to falsifying effort statistics over this period, hence data for all vessels for which corrected effort data could not be obtained were excluded from the database (Groeneveld, 1997).

The lobsters are caught using light, barrel-shaped plastic traps baited with fish heads and attached to a longline. Up to 200 traps can be deployed along a single longline (Pollock, 1994), and more than 20 longlines can be worked daily by the large vessels (J. Groeneveld, SFRI, pers. comm.). The traps are generally set for 24 hours before being hauled and re-set (Pollock and Augustyn, 1982), but in recent years it has been common practice to leave the traps in the water for longer periods of time (OLRAC, 1996). The relative frequency of multiples of 24 hour sets is shown in Table 36.

TABLE 36 : The relative frequency of the number of hours that traps are left in the water for the period 1977/78 - 1996/97.

SEASON	HOURS 0 - 24	25 - 48	49 - 72	> 72
	%			
77/78	94.3	4.0	1.0	0.7
78/79	94.8	3.1	1.4	0.7
79/80	88.5	7.0	2.0	2.6
80/81	90.0	6.6	1.7	1.6
81/82	93.8	5.3	0.4	0.5
82/83	93.0	3.9	1.7	1.4
83/84	93.1	4.3	1.7	0.8
84/85	97.9	0.9	0.7	0.5
85/86	98.3	0.8	0.2	0.8
86/87	98.5	0.6	0.0	0.9
87/88	97.9	0.0	0.6	1.5
88/89	98.6	0.2	0.2	1.0
89/90	88.7	3.3	1.3	6.7
90/91	85.9	4.1	1.6	8.3
91/92	79.4	11.1	2.0	7.5
92/93	72.3	18.8	2.4	6.6
93/94	69.8	23.8	1.5	4.8
94/95	81.8	11.5	1.7	5.0
95/96	71.7	17.1	2.9	8.3
96/97	53.8	34.0	3.8	8.3

Two types of fishing vessels fish for *P. gilchristi*: live lobster fishing vessels and freezer vessels that pack and freeze lobster tails. Freezer vessels generally stay at sea for 20 - 40 days, whereas the live lobster vessels carrying sea water tanks remain at sea for 2 - 10 days at a time (J. Groeneveld, SFRI, pers. comm.). Vessel size varies from between 20 and 60m in length and the number of vessels operating in the fishery varies from year to year, with typically between 12 and 16 vessels operating each year (J. Groeneveld, SFRI, pers. comm.). Four product categories are packed: lobster tails, live lobster, whole frozen cooked lobster and whole frozen raw lobster. The biggest market is currently for tails, followed by live and then whole frozen lobsters (Groeneveld, 1993).

The fishery is catch-limited in that a TAC has been set each year since 1984, and entry into the fishery is restricted to permit holders. The TAC is set in terms of tail mass, and masses of whole lobster are converted to tail mass by applying a constant conversion factor. The current conversion factor applied is 0.465, but Groeneveld and Goosen (1996) suggest that this should be revised to 0.45, implying a small increase in the mass of whole lobster required to fill the TAC.

There is no restriction on the size of *P. gilchristi* that can be caught, although the retention of egg-bearing females is prohibited (Pollock, 1994). Setting a size limit would be ineffective due to the variation in growth and size at maturity of lobsters between areas and the difficulties associated with enforcing and controlling different size limits in different areas (Pollock, 1994). Juveniles less than 55mm carapace length (CL) are infrequently caught, and it is assumed that they move onto the fishing grounds gradually at a CL of about 60mm either from deep (Groeneveld, in press) or shallow waters (Pollock and Augustyn, 1982).

16.2 The biology of P. gilchristi

P. gilchristi are very slow-growing with growth varying across areas, sex and lobster size (Groeneveld, in press). Growth increments decrease as lobster size increases, males growing marginally faster than females and lobsters on the Port Alfred fishing grounds growing substantially slower than lobsters elsewhere. Reasons for differential growth rates have not yet been investigated, but limited space (due to a narrow continental shelf) and increased intra-specific competition for available food on the Port Alfred grounds are thought to play a role. Groeneveld and Mellville-Smith (1994) estimate size at 50% maturity for females to be in the range of 61.7 - 70.9mm CL, the sizes-at-maturity being smallest in the east and becoming larger further west, and they suggest that this is due to the differential growth rates. The difference in sizes across areas suggest that extensive mixing within the population does not take place and this is reinforced by the fact that few tagged animals are recaptured far from their tagging position (Pollock and Augustyn, 1982).

Pollock and Augustyn (1982) report that fertilisation takes place externally, the male depositing a gelatinous spermatophore on the sternum of the female. Females of 90mm CL produce approximately 80 000 eggs (Pollock and Mellville-Smith, 1993), estimated from a relationship derived by Pollock and Augustyn (1982) which relates numbers of eggs to carapace length.

Groeneveld and Rossouw (1995) report that a single bimodally distributed breeding cycle is evident for small female *P. gilchristi*. A considerable percentage of large females appear to spawn in March, while females of all sizes spawn in July and August. The two spawning peaks for the large female *P. gilchristi* may be a result of spawning commencing early, and thereby protracting the breeding period, and resulting in females producing more broods per year as size increases (Groeneveld and Rossouw, 1995).

16.3 The South Coast rock lobster database

The data captured in the South Coast rock lobster database are shown in Table 37. As in the case of the hake fishery, a vessel characteristic database also exists for the South Coast rock lobster fishery, the information recorded in this database indicates whether and when echo-sounders, global positioning systems (GPS) and video plotters were installed on board each vessel.

TABLE 37 : The data captured in the South Coast rock lobster database.

Company code (a unique number identifying each company)

Vessel code (a unique number identifying each vessel)

Start date of voyage

End date of voyage

Set date (date on which the traps were set)

Grid number (the fishing grounds are divided into 10x10nm blocks so that catch positions can be reported accurately)

Area fished (i.e. zone)

Depth at which the lobsters were caught

Number of traps set (effort)

Number of hours traps were in the water (soak time)

Catch (kg) tail mass

The skippers of the vessels supply an estimate of the mass of lobsters caught each day, and these along with a more accurate mass measurement taken by inspectors who weigh the catch as it is off-loaded are submitted to SFRI to be captured in the database. The daily mass estimates made by the skipper are reconciled with the total mass measurement provided by the inspector, and it is this reconciled figure that is captured in the database (i.e. the skippers daily estimate is divided by the total skipper estimate for the trip to obtain a proportion of catch taken each day. This proportion is then multiplied by the inspector's (more accurate) total mass measurement and hence the catches apportioned across the days of the trip add up to the mass as determined by the inspector).

16.4 GLM analyses

GLMs have been applied to standardise the South Coast rock lobster CPUE data since 1995. The need for GLM analyses arose particularly as a result of colour echo sounders, line plotters and global positioning systems (GPS) being installed on the vessels over time which could potentially have an impact on their efficiency (Barkai and Bergh, 1994). It should be noted that the CPUE data for the year in which each GLM is performed are not included in the analysis since the fishing season for that year is not yet complete, and hence not all the data are available for inclusion in the model.

16.4.1 The 1995 GLM

The 1995 GLM was of the form:

$$ln(\text{CPUE}+\delta)= \alpha + \beta_{year}+\lambda_{zone}+\gamma_{season}+\rho_{comp}+\tau_{depth}+\omega_{echo}+\upsilon_{gps}+\phi_{video}+\text{interactions}+\epsilon \qquad \textbf{(40)}$$

where α is the intercept,

year is a factor with 15 levels (covering the split-year fishing season 1979/80 - 1993/94),

zone is a factor with 4 levels (corresponding to the four main fishing grounds),

season is a factor with 4 levels :
*seas*1 = October - December
*seas*2 = January - March
*seas*3 = April - June
*seas*4 = July - September,

comp is a factor with 4 levels (referring to the companies included in the analysis),

depth is a factor with 5 levels:
*d*75 : depth < 100
*d*125 : 100 <= depth < 150
*d*175 : 150 <= depth < 200
*d*225 : 200 <= depth < 250
*d*275 : depth >= 250,

echo refers to whether an echo-sounder is present or absent on board a vessel,

gps refers to whether a global positioning system is present or absent on board a vessel, *video* refers to whether a video plotter is present or absent on board a vessel,

ϵ is assumed to be normally distributed,

δ is a constant added to the CPUE to allow for the occurrence of zero CPUE values. It is assumed to be 10% of the average CPUE.

The interactions applied in the model included *year*zone*, *year*season*, *zone*season*, *season*echo*, *season*GPS* and *season*video* (the inclusion of these interactions were not necessarily all statistically justified. However, in the interests of consensus it was decided by the RLWG to retain them in the model). Interactions between all years and *seas*4 were not included in the analysis because in the earlier years no fishing took place in that season. Interactions between *seas*4 and the vessel electronic factors were therefore also excluded from the analysis.

Initially data were available for the period 1979/80 - 1993/94 and *year* was assumed to run from 1 October of one year to 30 September the following year over the entire time series. The data used in the analysis were constrained in that those records where effort was recorded as zero were deleted, data from companies 1 - 4 only were considered and only those records where soak time was $\leq$ 24 hours were included. Companies 5 - 7 were excluded from the analysis since they were considered to be minor companies with low levels of activity (contributing 1.8% to the total number of records in the database), and their quotas had often been fished by the major companies. The data pertaining to those vessels for which no information on vessel characteristics is available were also excluded from the analysis. For this analysis, n = 13250 and p = 116.

As in the case of hake (Section 7.5) a standard set of conditions was selected to represent the mean or "more common" conditions in order to determine the standardised CPUE. These were assumed to be *d*175 (depths of between 150 and 200m), company 3 and echo-sounder, GPS and video plotter all installed. The mean CPUE for a specific year was therefore calculated by summing over the four zones within a year and season, weighted by the total fishing area, and then summing over the four seasons and taking an average. Hence (Miyabe, 1994):

$$\overline{CPUE_y} = [\sum_k \sum_z (CPUE_{y,k,z} * Area_z)]/4 \qquad \textbf{(41)}$$

where $\overline{CPUE_y}$ is the zone weighted estimated CPUE in year y, and

$CPUE_{y,k,z}$ is the estimated CPUE for year y, season k and zone z.

The magnitudes of the fishing areas ($Area_z$) for various zones are as follows:

Zone 1 : 1681km^2

Zone 2 : 3461km^2

Zone 3 : 19208km^2

Zone 4 : 35477km^2

Equation 40 sets out a fairly crude analysis of the CPUE data in that there are order of magnitude differences between the sizes of the four zones considered. A large portion of the larger zones are not fished, and this problem is addressed later by refining the areal factor to a grid scale (as apposed to a zone scale) - see equation 45.

The results from the GLM indicated that 11.7% of the variance was explained by the model, and that CPUE had declined from 0.93 kg/trap in 1979/80 to 0.71 kg/trap in 1993/94.

Barkai and Bergh (1994) argued that there may be important differences in catch rates between vessels and therefore suggested that a vessel effect be included in the model. However, at the time that this analysis was performed the computer software available was unable to handle a large number of categorical variables. It was therefore considered defensible to include a company effect in the model as a surrogate for a vessel effect, assuming that the major difference in harvesting efficiency between vessels was a result of different harvesting policies for the different companies. With the improvement in computer facilities and software, OLRAC (1996) re-iterated the need to include a vessel effect in the model (obviously replacing the company effect with the vessel effect since including both effects in the model would result in confounding). This was considered for the next round of analyses.

16.4.2 The 1996 GLM

The same model as in equation 40 was applied to data for the period 1977/78 - 1994/95, i.e. two additional early years of data and the 1994/95 data were included in the analysis. The reason for the 1977/78 and 1978/79 data not being available for the previous analysis was that they were then still in the process of being validated. Furthermore, information on vessel characteristics for an additional 5 vessels was made available, allowing them to be included in the analysis. A more refined specification of the split-year fishing seasons was also defined and these are shown in Table 38.

TABLE 38 : South Coast rock lobster fishing seasons for the period 1977/78 - 1996/97.

Year	Date From		Date To
77/78	10/77	-	06/78
78/79	11/78	-	06/79
79/80	11/79	-	06/80
80/81	11/80	-	06/81
81/82	11/81	-	06/82
82/83	11/82	-	06/83
83/84	11/83	-	06/84
84/85	11/84	-	06/85
85/86	11/85	-	06/86
86/87	11/86	-	06/87
87/88	10/87	-	06/88
88/89	09/88	-	06/89
89/90	09/89	-	08/90
90/91	09/90	-	08/91
91/92	09/91	-	08/92
92/93	09/92	-	08/93
93/94	09/93	-	09/94
94/95	10/94	-	09/95
95/96	10/95	-	09/96
96/97	10/96	-	09/97

To take account of heteroscedasticity (Figure 27), it was assumed for the 1996 GLM that the variance of the residuals was related to effort, and the regression was weighted accordingly. This required an iterative process (described below) which was continued until convergence was achieved.

16.4.2.1 The log-likelihood function used to estimate the parameters of the error variance relationship to effort

It is assumed that the residuals, ϵ_i (each corresponding to a GLM fit of the data), follow a normal distribution with standard deviation σ_i, so that the likelihood, L, may be expressed as follows:

$$L = \Pi_i \frac{1}{\sqrt{2\pi}\sigma_i} e^{\frac{-\epsilon_i^2}{2\sigma_i^2}} \qquad \textbf{(42)}$$

Hence, after removing the constants and taking logs:

$$-lnL = \sum_i \left[ln\sigma_i + \frac{1}{2\sigma_i^2}\epsilon_i^2 \right] \qquad \textbf{(43)}$$

The residual variance σ_i^2 is modelled as $\sigma_i^2 = a + b/E_i$, where E_i is the effort recorded for observation i, i.e. the sum of a component with CV independent of sampling effort, and another reflecting Poisson-like sampling variability. The first of these factors is to reflect fluctuations in catchability whose effect would be independent of the level of effort applied, while the second relates to the sampling nature of the data obtained. If vector υ reflects the factors whose values are estimated when fitting the GLM, then the maximum likelihood estimate of parameters a, b and υ are attained by minimising the function:

$$-lnL(a,b,v) = \sum_i \frac{1}{2} ln(a + \frac{b}{E_i}) + \frac{\epsilon_i^2(v)}{2(a + \frac{b}{E_i})} \qquad \textbf{(44)}$$

This, however, is a non-linear function of some of its parameters. Since the software available could deal only with linear functions in fitting (i.e. the υ parameters), an *ad hoc* computational procedure was adopted to achieve overall maximisation as explained below.

16.4.2.2 The weighting procedure in the GLM

In a straightforward GLM fitting procedure, the residual sum of squares is calculated by minimising Σ_i (observed$_i$ - predicted$_i$ $)^2$, while a weighted residual sum of squares is calculated by minimising $\Sigma_i w_i$(observed$_i$ - predicted$_i$ $)^2$, where w_i is the inverse variance ($1/\sigma_i^2$, where σ_i^2 is defined above). The second term on the right hand side of equation 44 is of this form for fixed a and b.

The following procedure was therefore adopted to iteratively re-weight the residuals in equation 44 until convergence was attained.

1. The GLM was run to estimate υ with σ_i^2 = constant (i.e. $b = 0$), and the residuals were obtained.

2. The residuals and their corresponding effort values were fed into equation 44 to determine values for a and b through minimisation, and these were then used to calculate the weights, w_i, conditional on the estimates obtained in 1. for υ.

3. The GLM was then repeated with these weights accorded to each data point to re-estimate υ. These weights are the inverse of the variance, $1/\sigma_i^2$, which is equal to $1/(a+b/E_i)$, where a and b had been estimated in step 2.

4. Steps 2) and 3) were repeated until convergence occurred with respect to a and b.

This process amounts to minimising $-ln$L as a function of a and b for a given υ, then minimising on υ for these estimated a and b values, and repeating this process. This hopefully converges to a global minimum for $-ln$L as a function of a, b and υ - there was no indication of the presence of multiple minima given by the computations pursued.

The estimates of a and b obtained by minimising equation 44, and the resulting -*ln*L value obtained from the iterative process may be seen in Table 39 (n = 17502 and p = 134). There is no difference in the estimates of a and b between iterations 3 and 4, and the process was therefore halted at iteration 4. An r^2 of 13.6% was obtained for iteration 4.

TABLE 39 : Estimates for a, b and the associated -*lnL* obtained from the 1996 South Coast rock lobster GLM (equation 40). An iterative effort-weighted model was applied where weight, $w_i = 1/\sigma_i^2$.

Parameter	Base Case	Iteration 1	Iteration 2	Iteration 3	Iteration 4
a	0.221	0.223	0.213	0.213	0.213
b	96.87	96.00	106.59	107.08	107.08
-*lnL*	-1604.76	-1598.93	-1618.53	-1618.62	-1618.62

As suggested by OLRAC (1996), the company effect was replaced by a vessel effect (a factor with 40 levels) and the iterative weighting procedure was again applied. The estimates of a and b obtained by minimising equation 44, and the resulting -*lnL* value may be seen in Table 40. There is no difference in the estimates of a and b between iterations 3 and 4, and the process was therefore halted at iteration 4. An r^2 of 18.5% was obtained for iterative fit 4.

TABLE 40 : Estimates for *a*, *b* and the associated *-lnL* obtained from the 1996 South Coast rock lobster GLM (equation 40, with the company effect replaced by a vessel effect). An iterative effort-weighted model was applied where weight, $w_i = 1/\sigma_i^2$.

Parameter	Base Case	Iteration 1	Iteration 2	Iteration 3	Iteration 4
a	0.211	0.211	0.205	0.204	0.204
b	89.16	89.23	95.08	96.42	96.42
-lnL	-2117.38	-2110.45	-2127.87	-2127.86	-2127.86

The standardised CPUE time series obtained for the models incorporating company and vessel effects respectively are shown in Figure 28.

Given the options of incorporating a company or vessel effect in the GLM, the RLWG opted for the model which included the vessel effect since it resulted in a notably greater amount of variation (18.5% compared to 13.6%) being explained by the model.

A striking feature of Figure 28 is that the standardised CPUE for the model that incorporates a company effect indicates a much steeper downward trend since 1986/87 than does the model that includes a vessel effect. Butterworth and Clarke (1996) attempted to establish the underlying reason for this difference, investigating whether the average fishing power of the vessels fishing for each company had exhibited a trend over time. If this were the case, standardisation based upon a company effect only would not take account of this trend, whereas standardisation by vessel would. The effective average fishing power of the vessels for each company in each fishing season was calculated by Butterworth and Clarke (1996), who found that for all but one company the effective average fishing power of the vessels had declined over the period. They concluded that the trend in the standardised CPUE based on a model that included a company effect only was failing to allow for the (somewhat surprising) fact that companies were gradually switching to less efficient vessels over time. OLRAC and the South Coast Rock Lobster Association (1996) attributed this switch to the nature of the fishery, where intense inter-skipper competition and few economically and logistically viable fishing sites, most of which are small, lead to sub-optimal fishing practices. The inter-skipper competition arises from the fact that the skippers within a company are not allocated part of the company quota, but are paid on a commission basis for each ton landed (OLRAC and the South Coast Rock Lobster Association, 1996). Although this feature of the fishery was acknowledged, no immediate solution for taking it into account in the GLM was proposed.

16.4.3 The 1997 GLM

The 1995/96 data were included in the 1997 GLM, which took on the same form as that of equation 40, but with the company effect being replaced by a vessel effect. Given an additional years data, n = 18573 and p = 176. The iterative weighting scheme as applied for the 1996 GLM model was employed, where $w_i = 1/\sigma_i^2$.

The estimates of a and b obtained by minimising equation 44, and the resulting $-lnL$ value can be seen in Table 41. There is no difference in the estimates of a and b between weight iterations 1 and 2, and the procedure was therefore halted at iteration 2. An r^2 of 22.2% was obtained for iteration 2.

TABLE 41 : Estimates for a, b and the associated $-lnL$ obtained from the 1997 South Coast rock lobster GLM (equation 40 where company effect is replaced by vessel effect). An iterative effort-weighted model was applied where weight, $w_i = 1/\sigma_i^2$.

Parameter	Base Case	Iteration 1	Iteration 2
a	0.165	0.157	0.157
b	109.66	118.52	118.52
$-lnL$	-3320.27	-3339.91	-3339.85

The resulting standardised CPUE time series obtained from the 1997 GLM is shown in Figure 29.

Various sensitivity tests were undertaken with respect to the explanatory variables included in the model. For these sensitivity tests no effort-weighting procedure was applied.

The first sensitivity test was to consider the finer time scale of month as opposed to season, and all interactions with season were applied to the months instead. This was in response to a comment that variation in CPUE could be at a finer scale than the season level. Aggregation of some months was required because of the absence of data (Table 42).

TABLE 42 : Number of observations found in year-month combinations in the data being analysed.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
77/78	151	135	179	148	165	148	0	0	0	149	154	122
78/79	213	189	201	163	148	162	0	0	0	0	201	178
79/80	62	137	118	83	30	0	0	0	0	0	69	59
80/81	51	14	91	56	83	187	0	0	0	0	43	77
81/82	117	138	224	126	219	289	0	0	0	0	173	107
82/83	244	200	238	203	214	194	0	0	0	0	243	174
83/84	271	242	264	198	241	291	0	0	0	0	260	221
84/85	88	72	65	71	74	34	0	0	0	0	92	68
85/86	85	76	74	80	42	6	0	0	0	0	86	62
86/87	56	41	51	41	37	23	0	0	0	0	43	34
87/88	533	55	59	26	0	0	0	0	0	2	67	62
88/89	76	64	70	63	34	15	0	0	0	0	96	61
89/90	51	48	55	40	49	50	20	0	0	11	62	39
90/91	44	62	52	78	61	22	1	1	22	73	60	50
91/92	133	146	170	179	132	19	35	64	17	178	164	123
92/93	133	145	144	135	101	28	6	3	13	157	153	127
93/94	121	156	116	76	47	7	15	31	114	180	182	175
94/95	167	160	165	155	155	68	34	25	36	175	160	146

The following “months” were therefore defined:

*month*1 = January

*month*2 = February

*month*3 = March

*month*4 = April - June

*month*5 = July - September

*month*6 = October - November

*month*7 = December

The reason for lumping April - June was that in 1979/80 no fishing took place in June, whereas in 1987/88 no fishing took place in May or June. July - September were lumped together because that is how they were treated in the baseline 1997 GLM. No fishing took place in July - September over the period 1977/78 - 1988/89, and no fishing took place in August and September of 1989/90. October was lumped with November because no fishing took place in October for the periods 1978/79 - 1986/87 and 1988/89. No interactions between *month*5 and year and vessel characteristics were considered because of the absence of data for *month*5 in the early period (these are equivalent to the interactions between *seas*4, year and vessel characteristics).

The mean standardised CPUE for the month effect model was calculated by summing over the four zones within a year and month, weighted by the total fishing area for each zone, and then summing over the seven "months" and taking an average.

The amount of variation explained by this model was 22.9%, while that of the baseline model (equation 40, and excluding the iterative re-weighting procedure) was 20.4%, indicating relatively little difference in explanatory power between the two models. Of the seven "months" considered, four yielded parameter estimates that were significantly different from zero. Of the 85 year*month interactions only 27 of the parameter estimates were significantly different from zero. Figure 30 shows the standardised CPUE for the "season" and "month" models respectively, indicating very little difference in trend between the two. Based on these results it was recommended to and accepted by the RLWG that status quo be maintained by including the season effect in the analyses to standardise the CPUE.

The second sensitivity test involved excluding *seas*4 (July - September) from the calculation applied in standardising the CPUE because very little fishing took place in that season. The standardised CPUE including and excluding *seas*4 from the calculations are plotted in Figure 31 and indicate very little difference in trend between the two series. It was therefore decided to maintain consistency with previous years and retain *seas*4 in the CPUE standardisation calculations.

The third sensitivity test considered the exclusion all interactions from the model except for the year*zone interaction. This resulted in an r^2 of 17.7%, which is smaller than that of the full model (20.4%), and hence the RLWG decided to retain all interactions as were previously defined.

Bergh and Barkai (1997) suggested that the GLM be modified to take into account all factors (where possible in a GLM context) related to inter-skipper competition. It was argued that extra traps were being placed as a result of this competition, leading to effort saturation, i.e. an increase in nominal effort would decrease the CPUE. The following specific recommendations were made:

- that a finer spatial scale be considered, i.e. a grid level as opposed to a zonal level,
- that the number of traps used per set be included as a covariate in the model (to allow for possible saturation effects),
- that the different soak times be introduced as a categorical variable in the model, and
- that a *year***season* interaction be considered.

The model was therefore revised as follows:

$$ln(\text{CPUE}+\delta)= \alpha + \beta_{year}+ \lambda_{grid}+\gamma_{season}+\rho_{vess}+\tau_{depth} +\theta_{soak}+\eta(traps)+ \omega_{echo}+\upsilon_{gps}+\phi_{video}+\kappa_{year*season}+ \epsilon \qquad \textbf{(45)}$$

where the quantities are defined as for equation 40 and new quantities are

grid - a factor with 144 levels (for each grid block),

vess - a factor with 41 levels (for each vessel),

soak - a factor with 5 levels (referring to the soak time):

*Soak*1 : soak <= 24 hours
*Soak*2 : (24 < soak <= 48)
*Soak*3 : (48 < soak <= 72)
*Soak*4 : (72 < soak <= 96)

*Soak*5 : soak > 96 hours,

traps - a continuous variable associated with effort, and

*year*season* - year/season interaction.

Only data from companies 1 - 4 were included in the analysis, those records with zero effort were removed, and those grids with observations less than 0.1% of the total number of observations were excluded from the analysis because of possible lack of representivity in the light of the associated small sample size (OLRAC, pers. comm.). Note also that this model does not include many of the interaction terms considered in the previous model (given that the RLWG reconsidered its decision for the previous model in light of the lack of statistical significance of many of the associated parameters), and the absence of interactions with year means that it is assumed that the density distribution pattern remains unchanged over time.

At the time that this model was implemented additional data were available for analysis purposes; hence n = 20677, and p = 253.

The standardised CPUE for a specific year was calculated by averaging over the four seasons:

$$\overline{CPUE_y} = [\sum_s (CPUE_{y,s})]/4 \tag{46}$$

where $\overline{CPUE_y}$ is the standardised CPUE in year y, and

$CPUE_{y,s}$ is the estimated CPUE for year y and season s.

The standard set of conditions selected to compute the standardised CPUE were:

the median parameter estimate for the grid effect,

the median parameter estimate for the vessel effect,

*d*175 for the depth effect,

*Soak*1 for the soak effect, and

echo, gps and line are all installed.

The amount of variation explained by the model was 25.2% and a regression of *ln*(standardised CPUE) vs time indicated a decline in resource abundance of 1.6% per annum over the period 1977/78 - 1995/96. The resulting standardised CPUE time series obtained is shown in Figure 32 (the standardised CPUE obtained from the previous effort-weighted zone-based model is plotted for comparative purposes).

The effect on the trend of omitting the traps covariate from the model was also investigated. This model indicated a decline in resource abundance of 2.4% per annum compared to the 1.6% when the covariate is included. Both trends are shown in Figure 33 (each normalised to one), and indicate a substantial difference in trend depending on whether the trap effect is included or excluded from the model.

A plot of the average number of traps used per set each year is shown in Figure 34, indicating that there was a large increase in the average number of traps set in 1984/85 relative to previous years, and that since 1986/87 the average number of traps set per year has remained fairly constant. This increase is the reason for the lesser estimate of the rate of resource decline when the traps co-variate is included in the model. However, the RLWG was concerned about the reliability of this result, because of the possibility that there might be confounding with the trend in year effect parameters when the trap effect was included in the model if the average number of traps had increased equally across grids over time.

Further investigations were initiated to attempt to check whether there was indeed such confounding, and two approaches were considered. The first was to run the GLM, but treat the year effect as a continuous variable as opposed to a categot variable. In this way a standard error for the year parameter estimate (which reflects the abundance trend over time) can be obtained. This model was applied both including and excluding the trap effect, since if there was confounding, the variance would likely increase substantially when the trap effect was included in the model. The results indicated a coefficient of variation (CV) for the year parameter estimate of 9.3% for the model which excluded the trap effect and 13.7% for the model which included a trap effect. Thus, although the variance increased when the trap effect was included, it was not **dramatically** different (i.e. by order of magnitude) from the case where the trap effect was excluded.

The second approach was to fit a model of the form:

$$\text{traps}_i = \alpha + \beta_{year} + \lambda_{grid} + year*grid \tag{47}$$

where traps$_i$ refers to the number of traps,
α is the intercept,
year is a factor with 19 levels (covering the period 1977/78 - 1995/96),
grid is a factor with levels (for each grid block), and
*year*grid* is a year/grid interaction.

If there were very few significant *year*grid* interactions, this would imply that the time trend in the number of traps was virtually the same in all grids, i.e. that there is a confounding effect as trends in CPUE with year and with effort could not be distinguished. The results indicated that approximately 10% of the interactions were significant.

The results from the two approaches therefore suggested that there is no serious confounding effect, and hence the trap effect should be retained in the model.

Given the inclusion of the trap effect in the model, the inclusion of a *year*trap* interaction was investigated to determine whether there was evidence that the parameter associated with saturation effect changed over time. An r^2 of 25.9% was obtained and the slope of the standardised CPUE indicated that the resource was declining by 3% per annum over the full period considered (i.e. much more that the 1.6% per annum indicated by the model without these terms, but adding only 0.7% to the r^2). Note that in the standardisation calculation, the standard for the *year*trap* interaction was selected to be the average number of traps in each year multiplied by the parameter estimate for the corresponding *year*trap* interaction.

Considerable debate ensued in the RLWG as to whether or not these interaction terms should be included in the GLM. First, the functional form assumed for representing the trap effect was queried; because the GLM is used to represent CPUE with a constant added, rather than CPUE on its own, one would expect a "trap interference effect" relationship to be of the form:

$$ln(\text{CPUE} + \delta) \sim ln\,[e^{(-\beta * traps)} + \text{constant}] \qquad \textbf{(48)}$$

but, within the GLM framework we are modelling:

$$ln(\text{CPUE} + \delta) \sim -\beta * traps \qquad \textbf{(49)}$$

The GLM was therefore refit using $ln(\text{CPUE}+\delta) \sim ln(\beta * traps)$ rather than just $\beta * traps$. The results were very similar for the two options, indicating that within the range of data any "near-linear" relationship (as in equation 48) would do. It was also noted that only four of the 18 *year*trap* interaction parameters were significant: two in the early years prior to 1984 and two in the later years, which renders the inclusion of these terms questionable.

Furthermore, stemming from the fact that fewer traps were used in the earlier years than in the later years, plots of $ln(\text{CPUE}+\delta)$ against effort were examined for the two time periods. These indicated a small decline in $ln(\text{CPUE}+\delta)$ with number of traps used but no noticeable differences between the two periods (J. Powers, pers. comm.).

Based on these various results, it was agreed by the RLWG that a *year*trap* interaction not be included in the model, and the final model selected by the RLWG was therefore the one set out in equation 45.

CHAPTER 17 - THE WEST COAST ROCK LOBSTER RESOURCE

17.1 History of the South African fishery

Commercial exploitation of *Jasus lalandii* commenced at the turn of the 19th century (Pollock, 1986) and is currently the largest crustacean fishery in South Africa, making up 75% of the total crustacean catch (Crawford *et al.*, 1987). Figure 35 illustrates the history of catches in this fishery since its inception in 1870.

J. lalandii are distributed from about 23°S near Walvis Bay on the West Coast to about 28°E near East London on the South Coast (Pollock, 1986). Although there is no physical separation, those lobster stocks found north of the Orange River are managed by the Namibian authorities, while those found south of the Orange River are managed by the South African authorities.

Traditionally the South African fishing grounds were separated into eight Areas (Figure 36), covering those grounds on which *J. lalandii* occurred in commercial quantities, i.e. between 25°S in Namibia and 34°30'S near Cape Point (Pollock, 1994). Later, for management purposes, some of these Areas were combined into zones (Figure 36). Within zones, Areas which are geographically contiguous are managed as a unit, while those which are separated (Areas 7 & 8) are managed independently. Two further Areas (10 & 11) are also shown in Figure 36: these are Areas in which only a small amount of catch is taken, the former forming part of an experiment and the latter representing a traditional community quota.

Over time the fishery has moved away from the traditional northern Areas to the more southern Areas as the distribution patterns of the lobsters has changed (D. Schoeman, SFRI, pers. comm.), and it may extend even further south than the traditionally defined Areas in the future (it appears that *J. lalandii* also occur in commercial quantities between Cape Hangklip and Danger Point (Figure 36), and the viability of opening this Area up to commercial fishing is currently being investigated (D. Schoeman, SFRI, pers. comm.)).

The South African *J. lalandii* fishery is limited to shallow waters and catches are predominantly male. The lobsters are protected by a minimum legal size limit (Payne and Crawford, 1989) which has not remained static over the years. The small contribution (and sometimes even absence) of females in the catches in certain years is a result of the size limit imposed, since females grow at a much slower rate than males (Pollock, 1986), and therefore reach the legal size limit at a much later stage than do males. To ensure that undersize lobsters are not retained, the commercial catches are sorted aboard the fishing vessels by means of a deck grid sorter which returns these lobsters back into the ocean.

A minimum size limit of 89mm CL was introduced in 1933 for all Areas and a tail mass production quota was introduced in 1946 (Pollock, 1986). Catches declined in the late 1960s, particularly in the northern Areas (Areas 1 and 2), where a minimum legal size limit of 76mm CL had been in place since 1959 (Pollock, 1986). In 1970 the minimum size limit was re-set to 89mm CL for all Areas and the quota was reduced (Cockroft and Payne, 1997). In 1985/86 the size limit was reduced to 75mm CL in Areas 1 and 2 based on results from yield per recruit and egg production per recruit analyses (Pollock, 1994). The size limit in other Areas was reduced from 89mm CL to 80mm CL in 1992/93 as a result of the inability to fill quotas and in order to reduce the number of undersize fish being discarded, and this was revised in 1993/94 to 75mm CL based on results obtained from a size-based model (Anon, 1993). Other restrictions that apply to the fishery are that possession of egg-bearing and soft-shelled animals is prohibited, a closed season from 1 June - 31 October applies to Areas 1 - 6, and a closed season of 1 July - 14 November applies to Areas 7 and 8 (Pollock, 1994), although some flexibility is allowed in certain Areas to accommodate requirements of the Industry.

Pollock (1986) explains the fishing practices up until the early 1980s. He reports that prior to 1980 vessels were able to move freely across all Areas, although they tended to fish on home grounds. In 1978 however, large vessels from Areas 3 and 4 moved further south, to Area 7 in particular, as a result of a sudden decline in availability in Area 3 in 1977/78. This led to a steep increase in fishing effort in Area 7 and a subsequent decline in CPUE. To curb over-exploitation in this Area, the Industry agreed to impose a catch limit of 780t in Area 7 for the 1980/81 fishing season. An Association representing all companies and fishermen along the coast was formed, and management control in the form of TACs was introduced in the early 1980s. In addition, a whole lobster mass quota was introduced to replace the tail mass production quota (Cockroft and Payne, 1997).

A global TAC for the fishery is calculated each year and is then apportioned across zones A, B and C and Areas 7, 8, 10 and 11. The allocation of TAC to each zone/Area is generally based on past performance and resource indices obtained from each zone/Area, although Areas 10 and 11 are usually allocated a fixed amount of TAC each year (D. Schoeman, SFRI, pers. comm.). In order to allow some flexibility, a 15% tolerance is allowed, i.e. if catches in a particular Area are poor, remaining allocations may be caught in other Areas provided that actual catches in any Area do not exceed 15% of the original allocation to that Area. Policing to ensure that the portion of TAC allocated to each area is adhered to is left to the Industry, under the auspices of the Association (Pollock, 1986).

Two methods have been employed to catch *J. lalandii* over the history of the fishery: hoopnets and traps (Payne and Crawford, 1989). The traditional method of hoopnet fishing involves a small vessel (bakkie), propelled either by oars or an outboard motor, and carrying 2 - 3 fishermen at the most, who use nets baited with fish to catch the lobster. The nature of these vessels restricts fishing to inshore areas of depths less than 25m (Pollock, 1986). Bakkies can also be towed behind a mother vessel (deck-boat) to waters beyond their normal range where they are deployed to fish with hoopnets. This gear is left in the water for approximately half an hour before being retrieved (Payne and Crawford, 1989).

Trap vessels entered the fishery in the early 1970's (Pollock, 1986). These vary between 6 - 14 metres in length and are powered by inboard motors (Pollock, 1986 ; Payne and Crawford, 1989), allowing them to fish further offshore. Metal traps covered with polyethylene netting are baited with fish and set in water depths of up to 80m (Pollock, 1986). As many as 80 traps can be deployed twice a day by each vessel (Pollock, 1986). There are currently approximately 300 bakkies and 50 trap- and deck-boats operating in the fishery (D. van Zyl, SFRI, pers. comm.). The product derived from West Coast rock lobster fishery is separated into three categories : live lobster, lobster tails and cooked lobster. Current demand is primarily for live lobster.

The catch, effort and CPUE series for each method of fishing are shown in Tables 43 - 47 (van Zyl, 1996b), where each table refers to a particular Area (information from Areas 3 - 8 are presented in these Tables, since they are the Areas considered in the GLM analyses - see Section 17.3). The portion of the TAC allocated to each Area over the period shown is also included in each Table.

TABLE 43 : Catch, effort and CPUE series for *J. lalandii* in Area 3 for all methods of fishing. The TAC portion allocated to this Area for each season is also shown (source : van Zyl, 1996b).

*** denotes the portion of the TAC allocated to both Areas 3 and 4.**

			Trap			Deck-boat			Bakkie		
Season	TAC potion (tons)	Total catch (tons)	Catch (tons)	Effort # traps hauled	CPUE (t/trap hauled)	Catch (tons)	Effort # nets	CPUE t/net	Catch (tons)	Effort bakkie days	CPUE t/bakkie day
68/69		972	DATA UNRELIABLE								
69/70		818									
70/71		1309									
71/72		861									
72/73		858									
73/74		933									
74/75		1266	22	4963	4.46	547	106294	5.15			
75/76		1260	116	11017	10.52	293	58384	5.02			
76/77		714	267	85220	3.13	80	31197	2.58			26.50
77/78		320	225	81387	2.76	31	16605	1.84	73	7394	9.88
78/79		285	167	81918	2.04	44	18808	2.32	74	4528	16.39
79/80		103	71	29927	2.36	40	17282	2.31	38	2367	16.13
80/81		494	259	141895	1.83	49	42934	1.15	66	3574	18.47
81/82	450	463	182	79852	2.30	183	60645	3.00	42	1633	25.46
82/83	450	471	279	80919	3.40	143	42568	3.40	Catch and effort data were collected for these years, but they were not recorded (only the CPUE was recorded).		25.40
83/84	470	610	230	40414	5.70	227	39791	5.70			37.20
84/85	520	621	176	48296	3.70	266	60102	4.40			28.70
85/86	485	544	92	28479	3.21	160	54370	2.94			28.20
86/87	485	460	191	50431	3.78	257	55976	4.60			50.00
87/88	420	422	179	42878	4.17	244	49615	4.92	25	405	62.74
88/89	440	494	231	61480	3.76	175	49126	3.55	15	261	59.06
89/90	440	367	160	74333	2.15	156	60433	2.59	26	747	34.82
90/91	440	272	183	168498	1.09	60	43401	1.34	17	959	17.74
91/92	255	232	171	150850	1.13	37	19488	1.90	18	802	22.50
92/93	210	212	122	20262	6.01	79	12601	6.31	11	358	30.43
93/94	480*	5	0.8	188	4.45	1	488	2.89	3	75	36.94
94/95	494*	69	16	11757	1.32	44	8114	5.37	9	477	19.77
95/96	368*	13	7	2310	2.95	5	1232	3.69	0.9	52	17.03

TABLE 44 : Catch, effort and CPUE series for *J. lalandii* in Area 4 for all methods of fishing. The TAC portion allocated to this Area for each season is also shown (source : van Zyl, 1996b).
*** denotes the portion of the TAC allocated to both Areas 3 and 4.**

			Trap			Deck-boat			Bakkie		
Season	TAC portion (tons)	Total catch (tons)	Catch (tons)	Effort # traps hauled	CPUE (t/trap hauled)	Catch (tons)	Effort # nets	CPUE t/net	Catch (tons)	Effort bakkie days	CPUE t/bakkie day
68/69		206	DATA UNRELIABLE								
69/70		394									
70/71		538									
71/72		248									
72/73		434									
73/74		470									
74/75		673				4	600	6.52			
75/76		723	21	3180	6.67	159	33898	4.69			
76/77		534	23	7310	3.20	50	12766	3.93	460	1562	29.40
77/78		277	144	46923	3.08	27	10565	2.55	109	9534	11.45
78/79		452	153	60942	2.51	69	29448	2.51	230	11779	19.48
79/80		298	168	75050	2.23	27	18088	1.50	142	8271	17.19
80/81		455	256	110531	2.32	57	16064	3.54	223	8644	25.77
81/82	400	430	189	29803	6.30			17.8	176	2803	62.83
82/83	500	539	235	23779	9.90	47	2628	7.90	Catch and effort data were collected for these years, but they were not recorded (only the CPUE was recorded).		102.30
83/84	600	503	108	12924	8.40	61	7680	6.30			92.20
84/85	555	458	146	21369	6.80	51	8002	6.35			62.00
85/86	505	453	113	8494	13.27	21	3300	4.10			64.40
86/87	505	548	152	13501	11.28	26	6240	12.75	380	3704	79.50
87/88	580	623	151	11220	13.42	115	9014	5.43	219	3912	102.52
88/89	610	616	181	23605	7.65	114	20988	1.66	184	4974	74.26
89/90	580	460	215	39510	5.43	10	6276	1.24	40	3753	36.98
90/91	530	238	188	165749	1.13	11	8796	2.48	49	2773	10.73
91/92	223	280	185	106619	1.73	15	6092	6.57	92	2122	17.50
92/93	260	329	202	21470	9.43	35	5392	14.78	160	2826	43.12
93/94	480*	550	248	40228	6.16	142	9602	5.86	118	4403	56.65
94/95	494*	433	249	131359	1.90	66	11242	10.02	76	1688	26.79
95/96	368*	360	212	25087	8.44	72	7156				44.94

TABLE 45 : Catch, effort and CPUE series for *J. lalandii* in Areas 5 and 6 for all methods of fishing. The TAC portion allocated to these Areas for each season is also shown (source : van Zyl, 1996b).

			Trap			Deck-boat			Bakkie		
Season	TAC portion (tons)	Total catch (tons)	Catch (tons)	Effort # traps hauled	CPUE (t/trap hauled)	Catch (tons)	Effort # nets	CPUE t/net	Catch (tons)	Effort bakkie days	CPUE t/bakkie day
68/69		707	DATA UNRELIABLE								
69/70		866									
70/71		879									
71/72		1369									
72/73		1272									
73/74		702									
74/75		846	73	11108	6.57	329	29688	11.09			
75/76		1107	187	48423	3.85	36	9494	3.83			
76/77		1691	921	168386	5.47	436	112212	3.88	344	7923	43.43
77/78		2072	1045	241454	4.33	551	124685	4.42	477	9993	47.69
78/79		2169	1318	222876	5.91	500	78433	6.38	350	5615	62.39
79/80		2166	1132	242825	4.66	618	165493	3.73	468	9253	50.61
80/81		1819	847	232391	3.65	357	136840	2.61	416	10999	37.79
81/82	1600	1523	827	179507	4.60	227	93292	2.40	268	13668	19.63
82/83	1490	1377	656	156369	4.20	119	35884	3.30			
83/84	1290	1184	538	114679	4.70	1	240	3.90			
84/85	1205	1195	670	119655	5.60	227	37797	6.00			
85/86	1165	1140	648	96147	6.74	199	25110	7.92			
86/87	1060	1096	699	150162	4.65	200	35417	5.66			
87/88	1060	1079	698	111727	6.24	171	3570	47.79	196	2369	82.69
88/89	1100	1056	549	109489	5.02	2	480	4.55	147	1676	87.80
89/90	1030	763	471	126710	3.72				94	1449	64.72
90/91	1000	686	381	174486	2.18	31	10452	2.99	58	2127	27.28
91/92	641	607	361	198534	1.82	5	300	18.15	193	11141	17.30
92/93	456	488	369	120284	3.07	58	13058	4.40	62	1793	34.38
93/94	400	369	279	67708	4.12	45	13600	3.33	46	1650	27.78
94/95	123	130	101	43003	2.35	22	12712	1.75	7	799	8.80
95/96	60	54	48	18301	2.65				6	424	14.78

TABLE 46 : Catch, effort and CPUE series for *J. lalandii* in Area 7 for all methods of fishing. The TAC portion allocated to this Area for each season is also shown (source : van Zyl, 1996b).

			Trap			Deck-boat			Bakkie		
Season	TAC portion (tons)	Total catch (tons)	Catch (tons)	Effort # traps hauled	CPUE (t/trap hauled)	Catch (tons)	Effort # nets	CPUE t/net	Catch (tons)	Effort bakkie days	CPUE t/bakkie day
68/69		640	DATA UNRELIABLE								
69/70		946									
70/71		826									
71/72		918									
72/73		935									
73/74		1200									
74/75		873	852	128132	6.65	10	1600	6.12			
75/76		925	887	128270	6.92	7	1388	5.11			
76/77		1344	1330	166480	7.99	14	2240	6.38			
77/78		2115	1827	276376	6.61	279	46178	6.05	10	254	37.69
78/79		1480	1307	227103	5.75	173	22768	7.58	1	26	45.65
79/80		1360	649	280470	2.31	235	73280	3.21	1	46	23.91
80/81	780	781	774	197410	3.90						
81/82	600	645	626	102920	6.10						
82/83	700	753	627	59714	10.50	5	455	10.70			
83/84	800	833	707	60442	11.60						
84/85	880	900	658	54081	12.17	13	1900	6.61			
85/86	1000	1029	514	38131	13.46	59	9300	6.34			
86/87	1200	1220	937	98177	9.45	61	8600	7.05			
87/88	1000	958+	905	78962	11.45						
88/89	1030	1023	864	75855	11.38						
89/90	1050	1086	677	69905	9.68						
90/91	1050	716	303	96264	3.15	7	3312	2.01	9	165	56.80
91/92	657	504	267	77369	3.44	70	20936	3.31	10	402	24.79
92/93	384	378	378	67590	5.60				0.2	2	107.50
93/94	340	342	342	50474	6.77						
94/95	345	315	287	78408	3.66	28	4109	6.84			
95/96	265	266	264	37874	6.98	2	510	4.44	0.5	2	228.10

TABLE 47 : Catch, effort and CPUE series for *J. lalandii* in Area 8 for all methods of fishing. The TAC portion allocated to this Area for each season is also shown (source, van Zyl, 1996b). ** includes a 200t Diaz quota.

			Trap			Deck-boat			Bakkie		
Season	TAC portion (tons)	Total catch (tons)	Catch (tons)	Effort # traps hauled	CPUE (t/trap hauled)	Catch (tons)	Effort # nets	CPUE t/net	Catch (tons)	Effort bakkie days	CPUE t/bakkie day
68/69		414	DATA UNRELIABLE								
69/70		731									
70/71		661									
71/72		430									
72/73		628									
73/74		763									
74/75		960	666	62740	10.61	9	1860	4.72			
75/76		953	811	97020	8.36	6	2600	2.17			
76/77		1103	890	108621	8.19	7	3440	1.92	111	2537	43.87
77/78		1095	960	241550	3.97	1	480	2.32	133	2174	61.58
78/79		544	421	73452	5.74	11	2290	4.96	111	1491	74.62
79/80		780	998	133325	7.48				95	1259	75.40
80/81		886	723	200700	3.60	2	1260	1.57	89	1628	54.55
81/82	600	573	405	105840	3.80	6	1560	3.60	97	1342	72.23
82/83	500	500	391	85860	4.60	11	1400	7.70			
83/84	500	471	395	65641	6.00						
84/85	500	480	288	37797	7.60						
85/86	530	499	404	52953	7.63						
86/87	530	538	468	80876	5.78	13	2400	5.60			
87/88	550	543	425	49793	8.53				69	945	73.17
88/89	600	610	517	55799	9.25				85	1156	73.54
89/90	580	637	180	30996	5.80				54	504	107.40
90/91	630	995**	223	42242	5.27	2	96	15.81	60	705	85.04
91/92	799	767	515	103050	4.99				49	627	78.36
92/93	760	654	573	70258	8.15				82	751	108.70
93/94	880	827	716	81886	8.74				112	916	122.00
94/95	935	929	770	101743	7.56	5	378	13.30	154	893	172.80
95/96	747	424	327	34714	9.42	2	360	6.06	95	548	174.46

17.2 The biology of J. lalandii

Growth of *J. lalandii* varies between males and females, with males growing at a faster rate than females (Pollock, 1989). Growth increments in both males and females decrease as size increases, and increments for females are smaller than those for males (Pollock, 1986). As a result of males growing faster than females, they reach legal size at a much faster rate than females (Pollock, 1986). Cockcroft and Goosen (1995) report that females sacrifice growth in favour of egg-production. Zoutendyk (1990) reports that as reproductive output of females increases so growth decreases, with almost zero growth occurring in females of 110mm CL. Males are able to grow to 190mm CL and their maximum lifespan is 30 - 40 years (Pollock, 1989). Zero and negative growth increments can occur for *J. lalandii*, and appear to be related to adverse environmental conditions (Cockcroft and Goosen, 1995). Poor growth rates have been recorded over the past decade, and these have been attributed to a combination of exploitation and food availability (Pollock, Cockcroft and Goosen, in press). Exploitation has led to decreased growth rates, presumably as a result of limb loss due to the handling and discarding of undersize lobsters, which then expend more energy on limb regeneration than growth. Similarly, decreased growth rates may be attributed to less food being available e.g. Shannon *et al.* (1987) report on the decline in the biomass of ribbed mussels (*Aulacomya ater*) and shallow-water black mussels (*Choromytilus meridionalis*), the main diet of *J. lalandii*.

Moulting takes place at different times and frequencies for juvenile, male and female *J. lalandii*. Both male and female juveniles moult several times a year, the frequency of moults decreasing with increasing size (Pollock, 1986). Adult lobsters moult once a year, with males casting their shells in late spring or early summer, and the timing of moulting varying across Areas. Times of peak moulting are September in Areas 1 and 2, October in Areas 3 and 4 and November in Areas 7 and 8 (Pollock, 1986). Females moult between April and June (Pollock, 1986 ; 1989). In general, adult males moult approximately six months before adult females so that when mating takes place the males are in a hard shell state and the females are in a soft shell state (Pollock, 1986). Mating takes place shortly after the female has moulted and the eggs are fertilised internally with the sperm being deposited on the underside of the female carapace, gaining entry by means of fine channels in the soft exoskeleton of the female (Pollock, 1986 ; 1989). Females carry their eggs until hatching takes place in October/November (a female of 89mm CL carries approximately 190 000 eggs) (Pollock, 1986 ; 1989). Hatching appears to coincide with strong southerly winds which induce upwelling, allowing the larvae to be transported northwards and off-shore by means of ocean currents (Pollock, 1986). Large numbers of puerulus larvae are found inshore between December and April, with settlement occurring at depths of less that 10m (Pollock, 1986). Both male and female lobsters reach sexual maturity at about 60mm CL, about 4 years after settlement for the males and about 5 for the females (Pollock, 1986). Over this period the juvenile lobsters move progressively into deeper waters, arriving in adult dominated waters at the time of sexual maturity (Pollock, 1989).

Inshore/offshore migration occurs in association with moulting and breeding cycles (Pollock, 1986). Such migrations also occur in Elands Bay (Area 4) in response to poorly oxygenated bottom waters (Pollock, 1986). In combination with the decomposition of a severe red tide, this condition resulted in a "walkout" of lobsters onto the beaches at Elands Bay during 1997, with the number of lobsters stranded estimated to be greater than the TAC set for that season (van Zyl and Schoeman, 1997). In Areas 1 and 2, and along the Namibian coast, the lobsters are confined to inshore areas as a result of oxygen-depleted bottom waters (Pollock, 1987). This reduced habitat has led to over-crowding which has impacted growth, mortality and size-at-maturity (Pollock, 1987). Females reach sexual maturity at a smaller size in the northern areas than in the southern areas as a result of the oxygen depleted waters (Pollock, 1989).

17.3 The West Coast rock lobster databases

Three databases exist for recording commercial catch and effort information : a trap database, a deck-boat database and a bakkie database. The information contained in each of these databases is shown in Tables 48 - 50 respectively.

TABLE 48 : The information contained in the West Coast rock lobster trap database.

Date on which catch was taken

Form number (the forms filled in by the skippers are allocated numbers)

Scale number (the scales used to weigh the lobster are each allocated an identification number)

Quota code (each quota holder is allocated a code number)

Vessel name

Vessel registration number

Area in which catch was taken

Sub-area in which catch was taken (various locations within an Area have been identified for more accurate reporting of catches)

The number of traps set

The number of traps pulled

Catch (kg)

TABLE 49 : The information contained in the West Coast rock lobster deck-boat database.

Date on which catch was taken

Form number (the forms filled in by the skippers are allocated numbers)

Scale number (the scales used to weigh the lobster are each allocated an identification number)

Quota code (each quota holder is allocated a code number)

Vessel name

Vessel registration number

Area in which catch was taken

Sub-area in which catch was taken (various locations within an Area have been identified for more accurate reporting of catches)

The number of hoopnets on board each bakkie towed by the deck-boat

The number of the bakkie towed by the deck-boat

The total number of bakkies deployed

Catch (kg) made by each bakkie deployed

Total catch (kg)

TABLE 50 : The information contained in the West Coast rock lobster bakkie database.

Date on which catch was taken
Form number (the forms filled in by the skippers are allocated numbers)
Scale number (the scales used to weigh the lobster are each allocated an identification number)
Quota code (each quota holder is allocated a code number)
Vessel registration number
Number of hoopnets carried by the bakkie
Area in which catch was taken
Sub-area in which catch was taken (various locations within an Area have been identified for more accurate reporting of catches)
Catch (kg)

In the trap fishery the traps are generally set at night and hauled the next morning. It may however happen that when the traps are hauled the following morning the skipper feels that the catch is too small, and the traps would then be re-set during the day. In such circumstances the skipper reports that the traps were set once, but hauled twice (an instance referenced as a "double pull"), so that in the log books the number of traps hauled exceeds the number of traps that were set. The trap database has therefore been separated into three datasets for analysis purpose. The first dataset contains all the trap information (henceforth referred to as traps (all)), the second dataset excludes all records where the number of traps pulled exceeds the number of traps set (henceforth referred to as traps (no double)), and the third dataset includes only those records where the number of traps pulled is equal to the number of traps set (henceforth referred to as traps (pull=set)).

Initially an effort-weighted commercial trap CPUE series was the only index of abundance used in the size-based assessment model for the west coast rock lobster resource, based on the fact that more than 80% of the catch in Areas 3 - 8 was taken with traps (Johnston and Butterworth, 1995). Areas 1 and 2 were not considered in this index of resource status because these two Areas are primarily hoopnet fishing Areas (D. van Zyl, SFRI, pers. comm.). In recent years, however, the percentage of the catch taken by hoopnets in Areas 3 - 8 has increased (Barkai and

Bergh, 1996), so that arguments were made that account should be taken of these data. Butterworth (1996a) developed an *ad hoc* approach to obtain a composite CPUE index of abundance based on data from the traps, deck-boats and bakkies. This method essentially involved area-weighting the CPUE for each method employed, normalising each series and then combining them by means of two catch-weighting methods (both of which yielded similar results). Two of these catch-weighted series were considered in the size-based model : the trap (no double) combined with the bakkie and deck-boat CPUE, and the trap (pull=set) combined with the bakkie and deck-boat CPUE (Johnston, 1996d). The area-weighted trap (no double) and trap (pull = set) were also considered in the size-based assessment model (Johnston, 1996d).

General linear modelling has subsequently been employed to derive a combined index of abundance from the various CPUE data sources.

17.4 GLM analyses

17.4.1 The 1996 GLM

The bakkie and deck-boat CPUE data for the period 1987/88 - 1995/96 in Tables 43 - 47 were analysed by means of general linear modelling in order to derive a combined index of abundance. Data prior to 1987/88 were excluded from the analyses since there is little data for the early years (see Tables 43 - 47) and these data are in any case considered to be less reliable (D. van Zyl, SFRI, pers. comm.).

The model applied to the bakkie and deck-boat data was:

$$ln(\text{CPUE}) = \alpha + \beta_{year} + \gamma_{Area} + \lambda_{method} + \epsilon \qquad \textbf{(50)}$$

where α is the intercept,

year covers the period 1987/88 - 1995/96, *Area* corresponds to Area 3, Area 4, Areas 5&6 combined, area 7 and Area 8,

method refers to whether a deck-boat or bakkie was used, and

ϵ is the error term which is assumed to be normally distributed.

Here $n = 72$ and $p = 14$. All the explanatory variables in equation 50 are categorical, and season 87/88, the deck-boat method of fishing and Area 3 were included in the intercept. In this case no δ adjustment was necessary since there were no zero catches.

The combined CPUE index for the two hoopnet fishing methods was then provided by the equation $e^{(intercept + \beta_{year})}$. This CPUE series is shown in Figure 37. This index, along with the area-weighted trap CPUE series was used as an index of abundance in the size-based assessment model.

17.4.2 The 1997 GLM

In 1997 the RLWG was given the option of repeating the 1996 analyses, i.e. catch-weighting the trap, bakkie and deck-boat CPUE or performing a more detailed GLM analysis which could allow for the incorporation of interactions. The latter option was preferred.

It was assumed that the fishing season ran from November of one year to September of the following year for all years considered in the analysis. Data covering the period 1993/94 - 1996/97 were included in the analysis. Data prior to 1993/94 were excluded for better comparability because they corresponded to periods of a different minimum legal size (see Section 17.1).

The CPUE for each of the fishing methods was defined as follows : catch divided by number of traps pulled for the trap data (i.e. catch/pull), catch per bakkie day for the bakkie data (each record is considered a bakkie day, and therefore CPUE = catch) and catch per bakkie for the deck-boat data (i.e. catch/total number of bakkies deployed).

The trap data were screened to determine if any records had zero pulls (effort) recorded. It was assumed that for the zero pull records the traps were lost to the fishery, and these records were therefore omitted from the analysis.

The model applied to the data was expressed as:

$$ln(\text{CPUE}+\delta) = \alpha + \beta_{year} + \gamma_{month} + \kappa_{Area} + \lambda_{method} + \tau_{type} + year{*}Area + month{*}Area + \epsilon \quad \textbf{(51)}$$

where α is the intercept,

year is a factor with 4 levels (covering the period 1993/4 - 1996/7),

month is a factor with 7 levels,

Area is a factor with 6 levels (covering Area 3 - Area 8),

method is a factor with 3 levels (referring to the fishing method employed - trap, bakkie or deck-boat),

type is relevant to trap fishing and refers to whether single or double pulls occurred (a single pull is defined as number of traps pulled <= number of traps set, while a double pull is defined as number of traps pulled > number of traps set),

*year*Area* is the year/area interaction,

*month*Area* is the month/area interaction,

ϵ is the error term which is assumed to be normally distributed, and

δ is a constant added to CPUE to allow for the occurrence of zero CPUE. δ is taken to be 35% of the average CPUE since for a range of δ values tested, this resulted in residuals that were closest to normally distributed (defined by skewness closest to zero).

A number of empty cells existed for certain month/Area combinations (Table 51) and months 6 - 9 were therefore lumped with month 5. Furthermore, there were no data for the month 5 - Area

3 combination, so for the standardisation procedure it was assumed that the parameter value for this cell was equal to the estimate for the month 5 Area 4 combination. In this analysis, n = 35845 and p = 62.

TABLE 51 : Number of observations for each month/Area combination in the West Coast rock lobster trap, bakkie and deck-boat datasets for the period 1993/94 - 1996/97.

	AREA						
MONTH	3	4	5	6	7	8	TOTAL
1	149	3614	1197	573	966	901	7400
2	179	2059	438	273	758	1026	4733
3	293	1635	358	179	379	1331	4175
4	19	503	202	53	70	1290	2137
5		69	34	37	79	1106	1325
6					25	824	849
7						500	500
8						272	272
9						13	13
11	307	3767	708	676	54	274	6086
12	188	4653	1273	954	855	433	8356
TOTAL	1135	16300	4210	2745	3486	7970	35846

The average standardised CPUE was calculated by summing over the 6 Areas within a year and month, weighted by the size of the Area, and then summing over the 7 "months" (i.e. the number remaining after some months had been pooled) and taking an average. The standard set of conditions assumed was:

average method = bakkies, and
type = single pulls.

Hence

$$CPUE_y = (\Sigma_m \Sigma_a [CPUE_{y,m,a} * A_a] / 7 \quad \textbf{(52)}$$

where $CPUE_y$ is the area-weighted estimated CPUE in year y,

$CPUE_{y,m,a}$ is the GLM-estimated CPUE for year y, month m and Area a (using equation 51) and,

A_a is the size of the Area:

Area 3	Area 4	Area 5	Area 6	Area 7	Area 8
1774 km^2	318 km^2	1392 km^2	643 km^2	2855 km^2	2621 km^2

The resulting CPUE series is shown in Figure 38.

A variant of the model in equation 51 was investigated, where an additional interaction of *year*method* was considered. The proportion of variance explained by this model was 70.8%, while the proportion explained by the model in equation 51 was 70.5%. Based on the fact that the inclusion of the *year*method* interaction produced no marked improvement in the fit of the model, it was suggested and accepted by the RLWG that a *year*method* interaction be excluded, and that the model of equation 51 be adopted as the standard for the provision of an index of resource abundance.

CHAPTER 18 - GENERAL CONCLUSIONS

Over recent years annual assessments have been carried out for the South Coast rock lobster resource, and on each occasion various GLM analyses of the CPUE data have been requested. The intention has been to define a standard GLM to be applied routinely, but the complexities associated with the data and the fishery have made it difficult to achieve this aim, and various additional factors have been incorporated in the model to take account of further effects as their pertinence became evident with further research over time.

GLM analyses were first applied to the South Coast rock lobster CPUE data to take account of the possible impact that echo sounders, global positioning systems and GPS may have had on the efficiency of the vessels as these features were installed on the fishing vessels over time. In the course of these analyses it was found that the average efficiency of the vessels in use had declined (Butterworth and Clarke, 1996), and this was attributed to inter-skipper competition (arising out of the fact that skippers are paid on a commission basis for each ton landed) which led to sub-optimal fishing practices. Skippers were placing extra traps to prevent others from fishing in an area, and it was argued that these extra traps were resulting in effort saturation (and hence a greater decline in CPUE than in resource abundance).

The inter-skipper competition nature of the fishery was afforded much debate, and it was suggested that all effects related to such competition (where possible) be taken into account in the GLM. This resulted in a fairly substantial revision of the GLM with the following effects being considered:

- a finer areal scale (at a grid rather than a zonal level),
- the number of traps used per set (to take account of possible saturation effects),
- soak time (i.e. the amount of time the traps were left in the water), and
- a *year*season* interaction.

The saturation effect, in particular, was afforded much debate. There was concern that there might be confounding in the trend in the year effect parameters if the number of traps had increased equally across fishing grids over time. Various methods were employed to test this, and the conclusion reached was that there was no serious confounding, so that the trap effect could be retained as a covariate in the model.

In light of the complications detailed above, it has been difficult to apply a standard GLM each year for the purposes of determining an abundance index for the South Coast rock lobster resource to be used in the assessment model. The Industry is of the opinion that the decline in CPUE over the past few years (as indicated in Figure 32) is more a consequence of changes in fishing strategy than a decline in resource biomass, and has proposed to test this by voluntarily reducing effort by at least 20% in the forthcoming fishing season (South Coast Rock Lobster Association, 1998). Butterworth and Brown (1998), however, point out that results from such and exercise are potentially confounded since an increase in CPUE could be reflective of the expected results given the saturation hypothesis, or of inter-annual fluctuations in catchability. They suggest rather that the Industry develop an experimental design, given the associated practical constraints, that is capable of eliminating potentially confounding influences by including periods both with and without this effort decrease within the same year.

A further model worth considering (as suggested by one examiner of this thesis) is to define regions (probably of different sizes) which are larger than the grids, and ensuring that there is complete coverage each year in these regions, to allow for a year*region interaction term.

The application of GLMs for the West Coast rock lobster resource was mainly for the purpose of deriving a combined index of abundance given that various fishing methods are employed in this fishery to catch the lobsters.

Trap fishing has for the last two decades been the more dominant method employed to catch the lobsters, and initially only an effort-weighted trap CPUE series was used as an index of abundance in the size-based assessment model used to assess the status of this resource. It became evident, however, that over very recent years increasing use was being made of hoopnet fishing, and an *ad hoc* approach was therefore developed to obtain a composite index of abundance based on both the trap and hoopnet CPUE data (Butterworth, 1996a). This method involved area-weighting each CPUE series, normalising them to one and then applying some form of catch-weighting to derive a composite CPUE index to be used in the assessment model.

Following this, a GLM was applied to the two methods of hoopnet fishing to derive a combined index of abundance, and this index along with an area-weighted trap CPUE index was used as an index of abundance in the assessment model. Subsequently, the trap CPUE series has been included along with the two hoopnet series in a more detailed GLM analysis which allows for the incorporation of interactions. This GLM has since been adopted as the standard GLM to be applied for the duration of the current OMP (1998 - 2000) that is in place for the management of the West Coast rock lobster resource.

For both the West and the more recent South Coast rock lobster GLMs, it has been assumed that the residuals obtained from the regression have constant variance, i.e. are homoscedastic (although at one stage for the South Coast analyses an iterative effort weighting procedure was applied to take account of possible heteroscedasticity). It may therefore be useful in the future to consider alternative error structure models, e.g. delta-lognormal and negative binomial, as well as to re-visit the iterative effort-weighting procedure to assess which is the most statistically defensible in terms of the variance structure shown by the residuals.

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UNPUBLISHED WORKING GROUP DOCUMENTS AUTHORED/CO-AUTHORED BY THE WRITER OF THIS THESIS

Below is a list of unpublished working group documents authored/co-authored by the writer of this thesis. The work that is reported in this thesis constitutes, *inter alia*, a consolidation of these documents.

BROWN, J.P. 1996. Effort weighted general linear modelling applied to the South Coast rock lobster CPUE data. *Unpublished Sea Fisheries Research Institute Rock Lobster Working Group Document, WG/03/96/SCL8* : 9pp.

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FIGURES

FIGURE 1 : The commercial CPUE series and summer survey biomass indices for West Coast hake (a biomass estimate for 1989 is not available as a result of that survey being aborted).

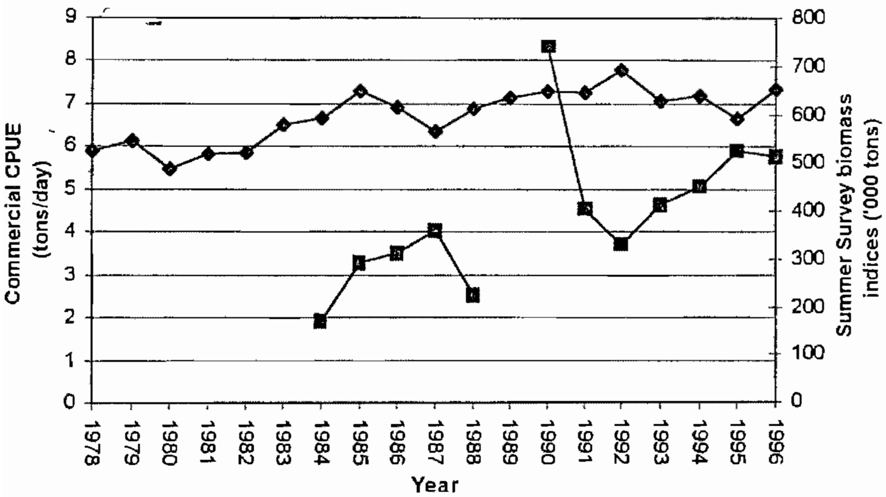


FIGURE 2 : The ICSEAF Convention Area and its statistical Divisions (Source : De Villiers, 1985).

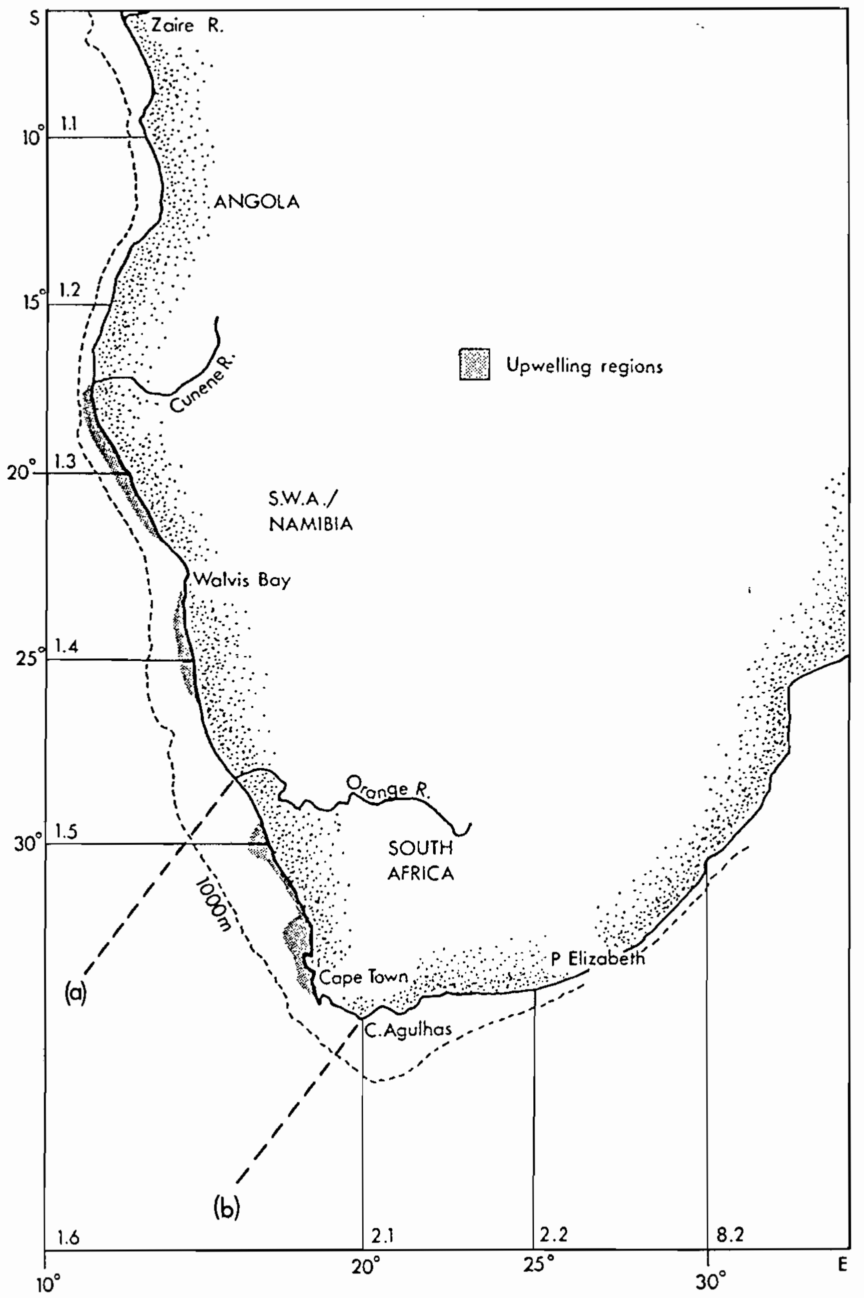


FIGURE 3 : Commercial catch rates of Cape hake off the West Coast of South Africa by time of day (a) in non-spawning season, (b) in the spawning season (after Botha, 1970) (source : Payne and Punt, 1995).

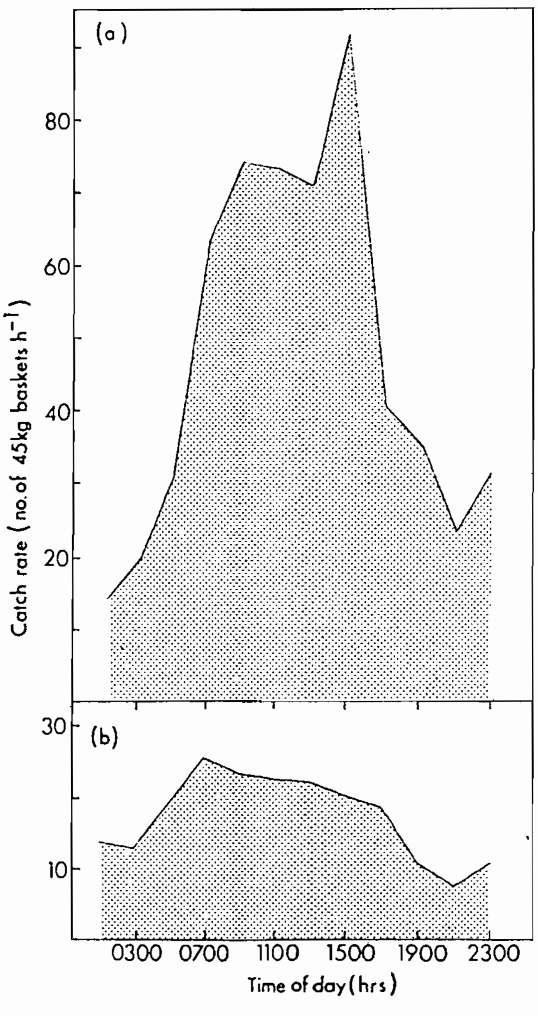


FIGURE 4 : The West Coast hake CPUE time series (standardised by means of applying the power factors that were crudely calculated many years ago).

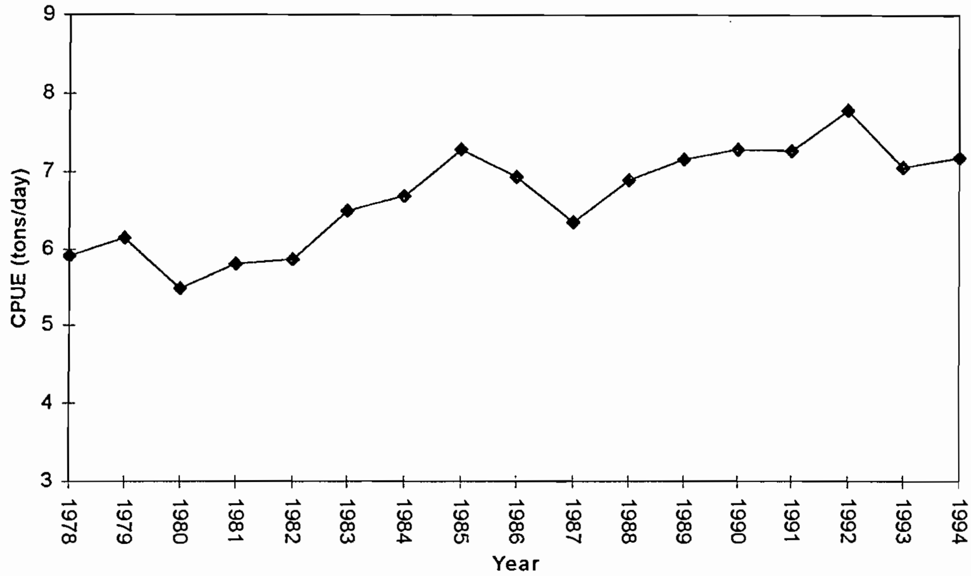


FIGURE 5 : Hake catch as a proportion of total catch, and hake directed effort as a proportion of total effort for the West Coast hake fishery.

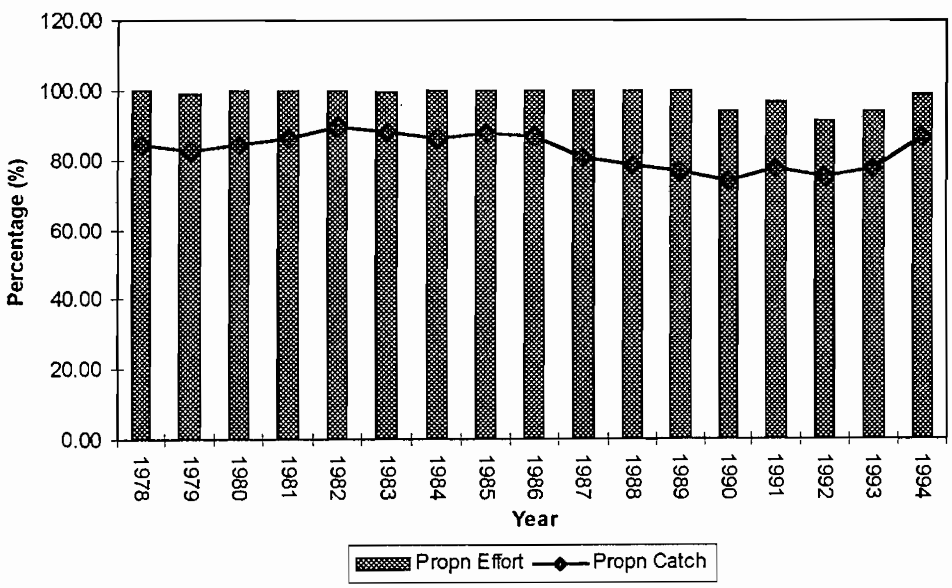


FIGURE 6 : Average depth per year of fishing for hake on the West Coast (hake targeted drags).

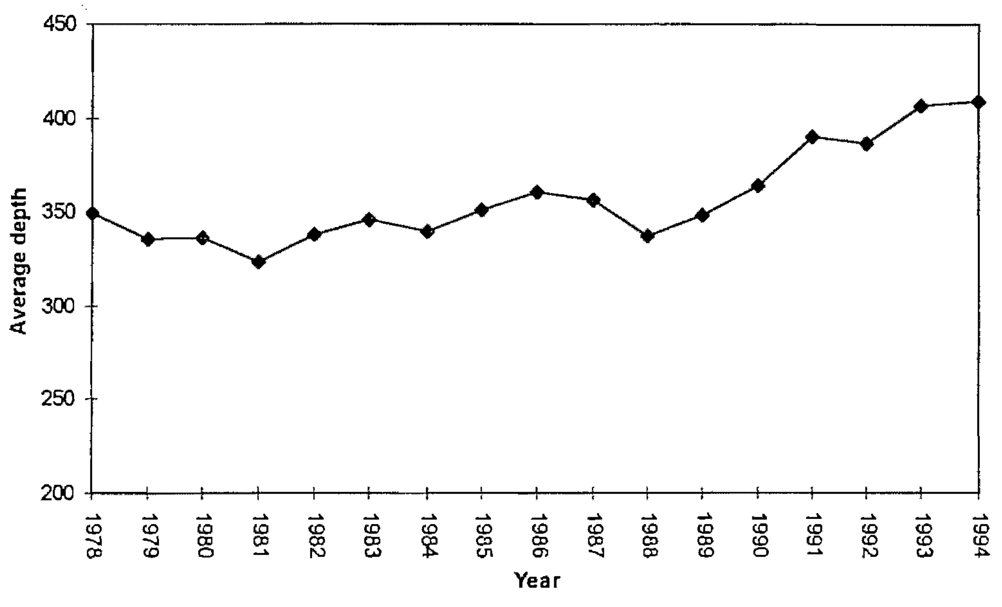


FIGURE 7a : Average West Coast hake CPUE and bycatch CPUE in 5 percentile intervals.

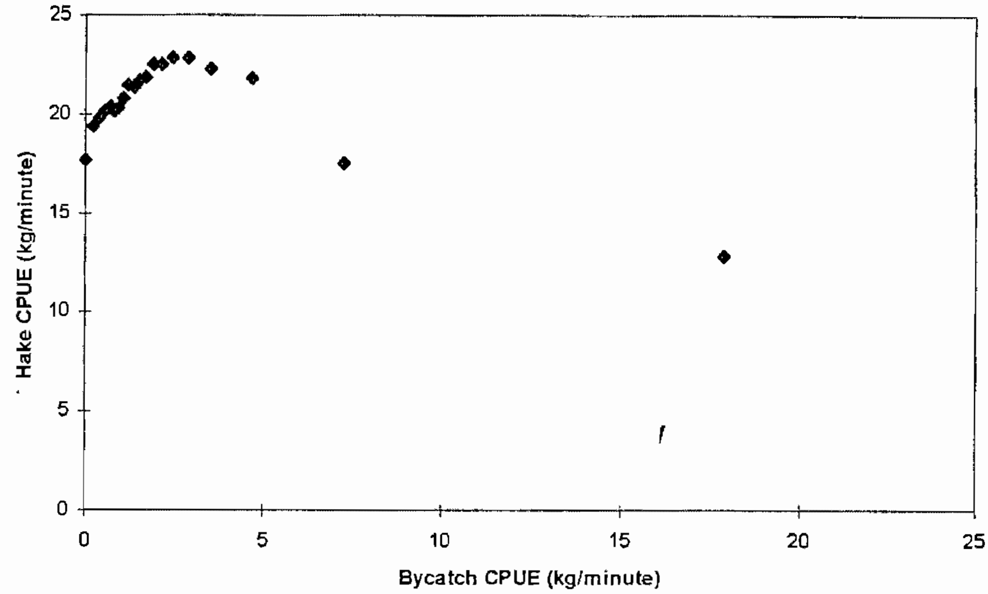
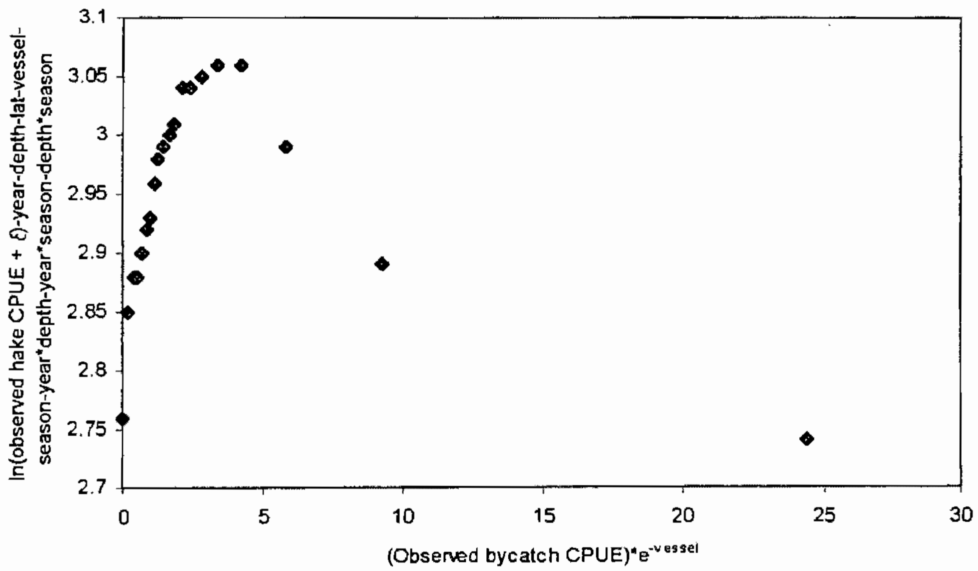
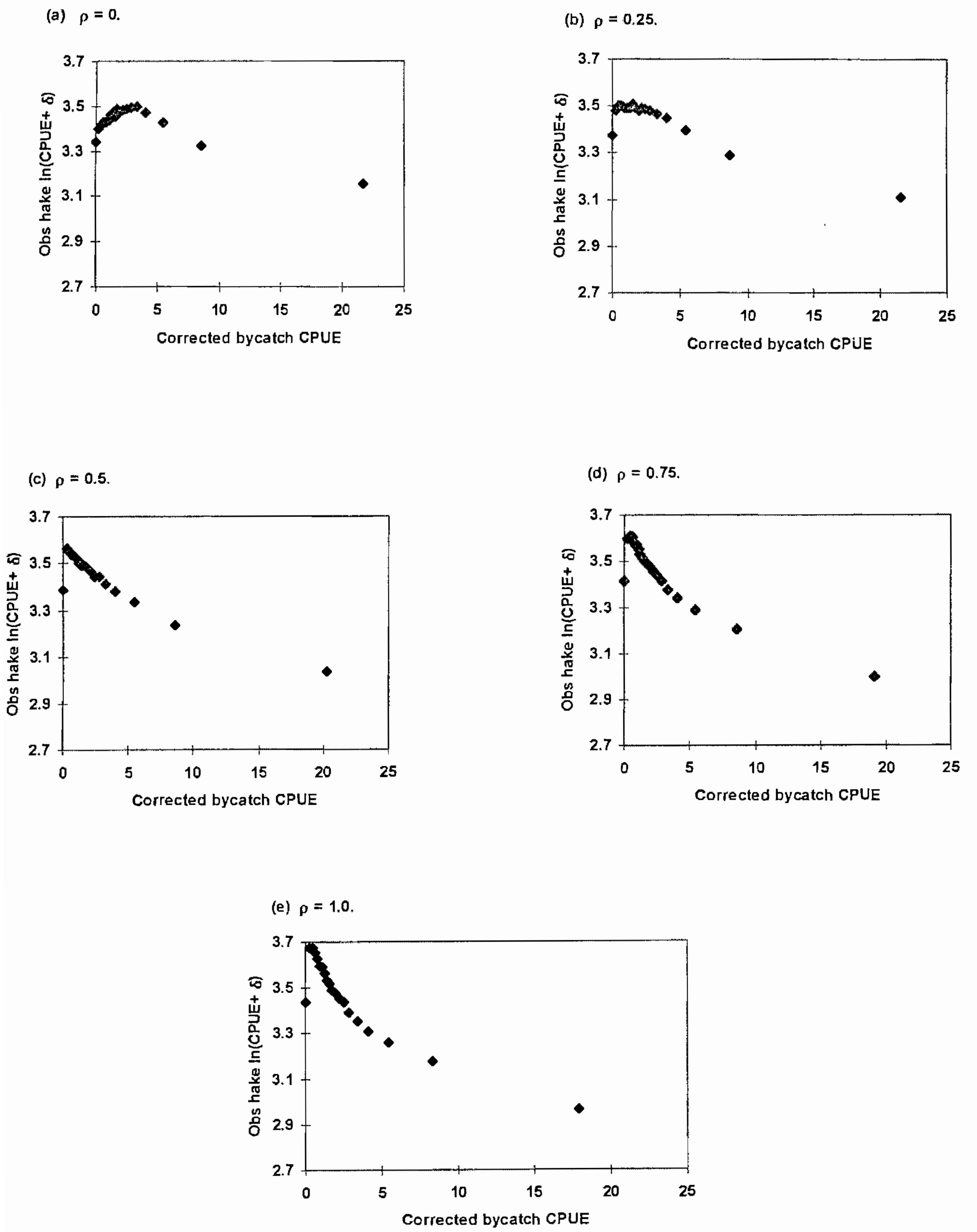


Figure 7b: Standardised hake CPUE vs observed bycatch CPUE (corrected for vessel effects)

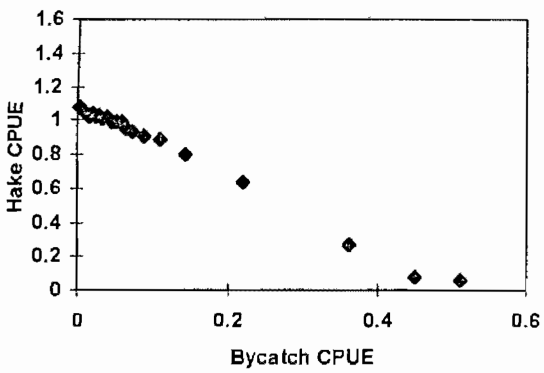


FIGURES 8a - e : West Coast vessel-factor-corrected observed hake *ln*(CPUE+δ) vs corrected bycatch CPUE for various ρ options.

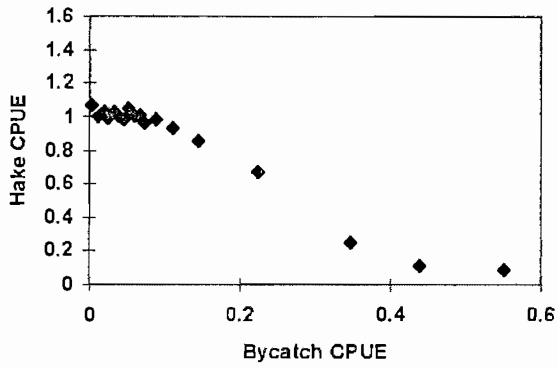


FIGURES 9a - e: The relationship between the simulated hake and bycatch CPUE data for $\rho = 1$ and various σ, ω and hake biomass options.

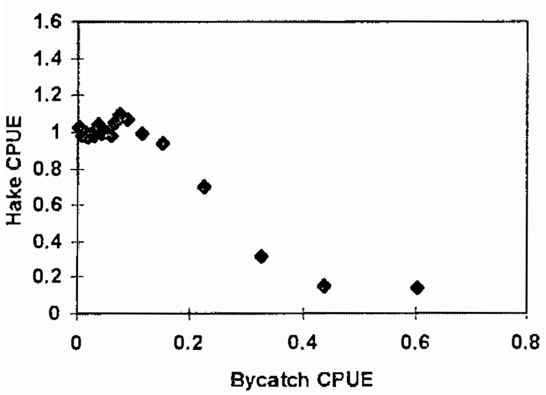
(a) $\sigma = 0.1$, $\omega = 0.007$ and hake biomass increases by 1% per annum.



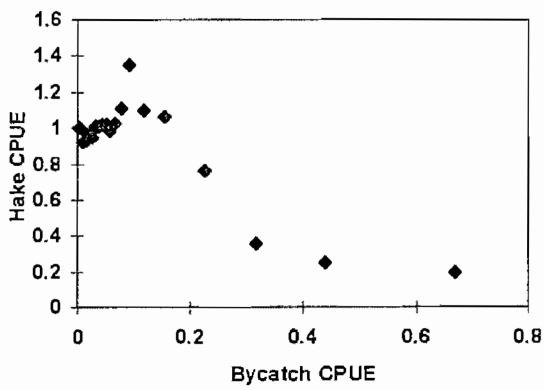
(b) $\sigma = 0.2$, $\omega = 0.007$ and hake biomass increases by 1% per annum.



(c) $\sigma = 0.3$, $\omega = 0.007$ and hake biomass increases by 1% per annum.



(d) $\sigma = 0.4$, $\omega = 0.007$ and hake biomass increases by 1% per annum.



(e) $\sigma = 0.5$, $\omega = 0.007$ and hake biomass increases by 1% per annum.

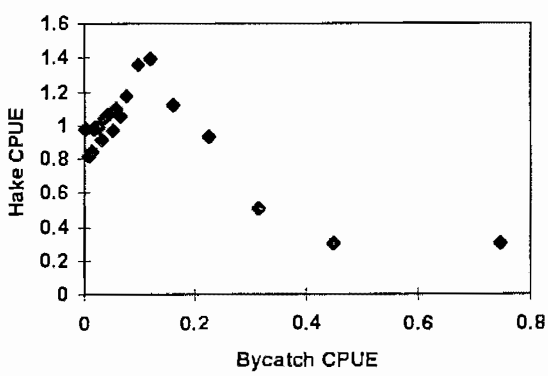


FIGURE 10 : Plot of $ax+bx^2+c$, where x is the bycatch CPUE, for each iteration (I1 to I10) in the West Coast hake CPUE analysis where ρ = 0.75. *a* and *b* refer to the bycatch CPUE and (bycatch CPUE)^2 parameter estimates obtained from the model respectively.

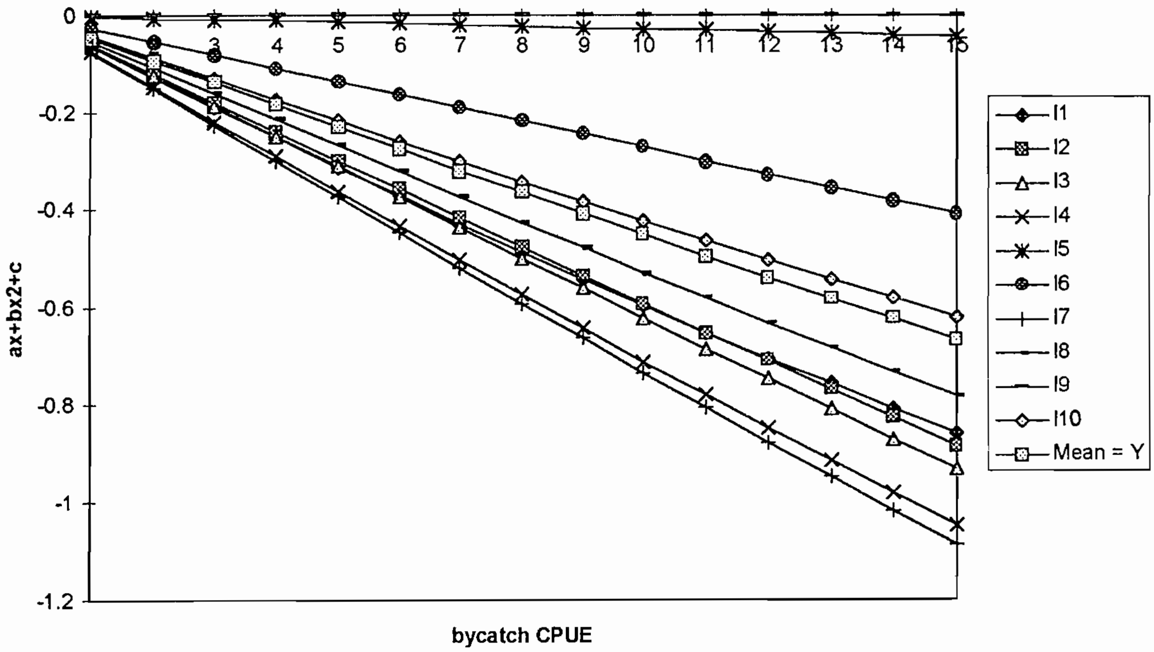


FIGURE 11 : Standardised base case (5) West Coast hake CPUE series.

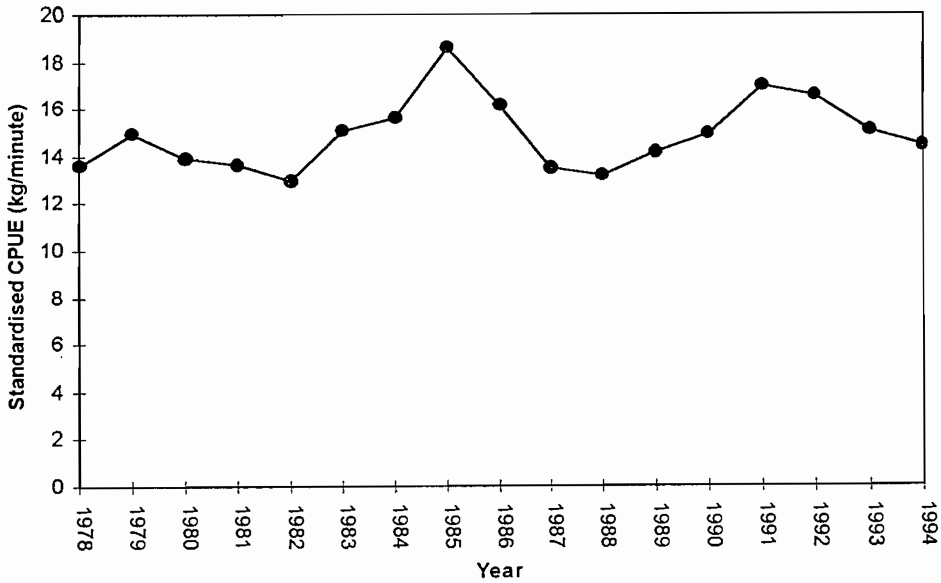


FIGURE 12 : Average observed West Coast small hake CPUE vs (medium+large) hake CPUE in 5 percentile intervals.

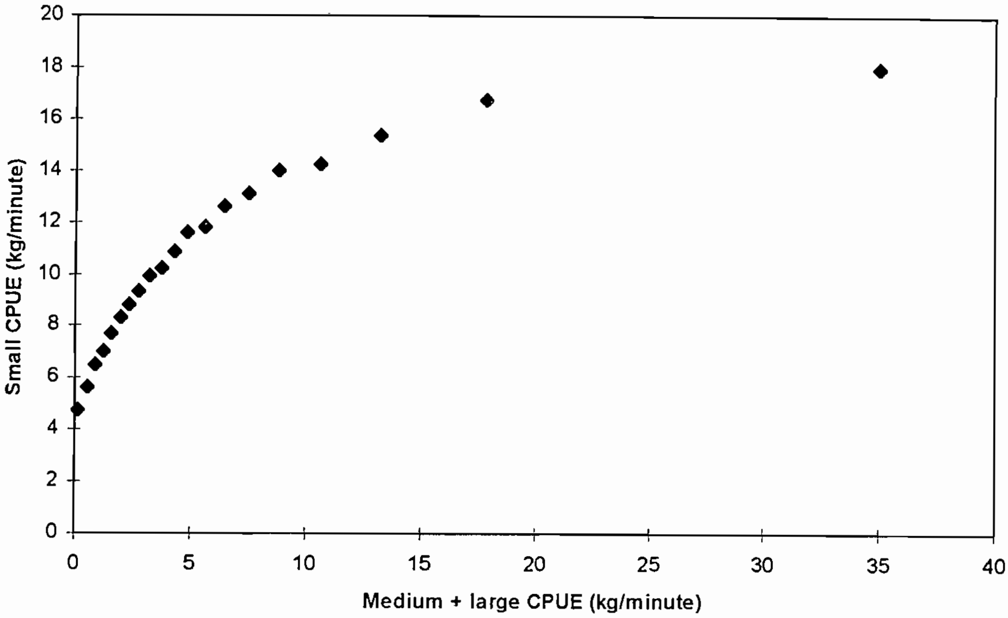


FIGURE 13 : Average observed West Coast (medium + large) hake CPUE vs small hake CPUE in 5 percentile intervals.

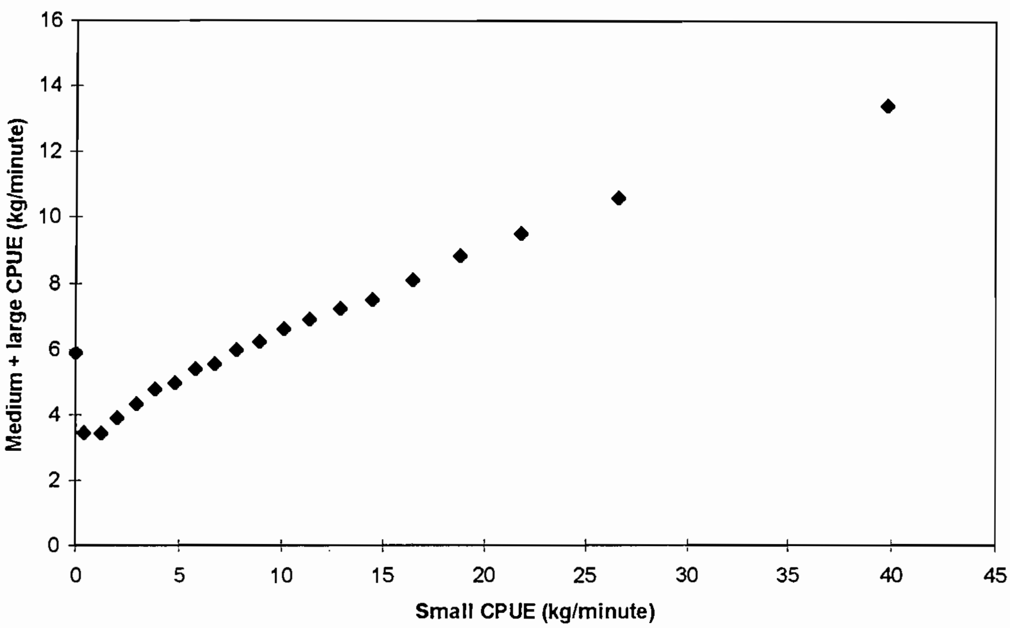


FIGURE 14 : Standardised CPUE of the West Coast small and medium+large hake categories.

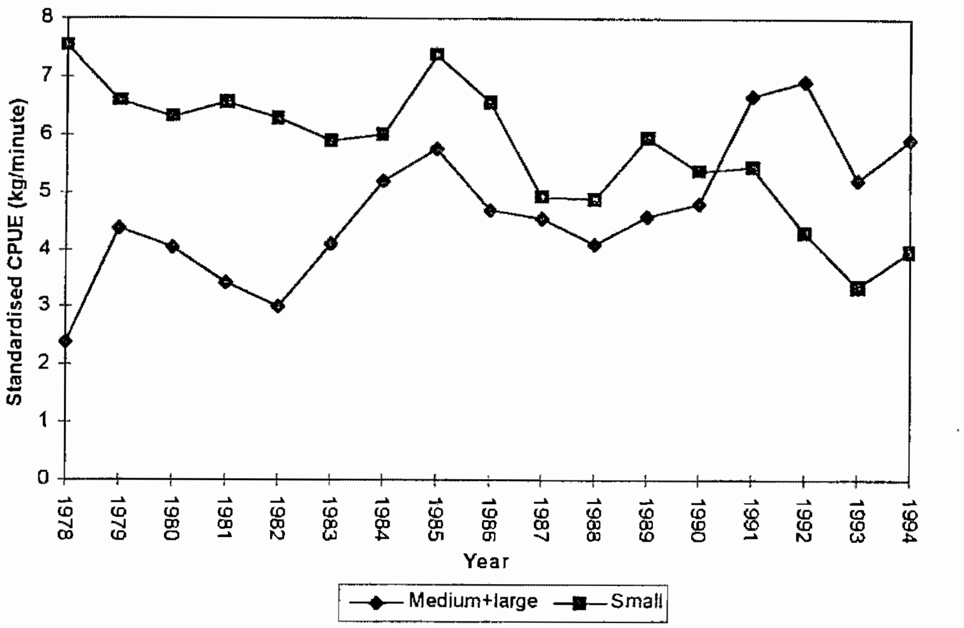


FIGURE 15: Average South Coast hake CPUE and bycatch CPUE in 5 percentile intervals.

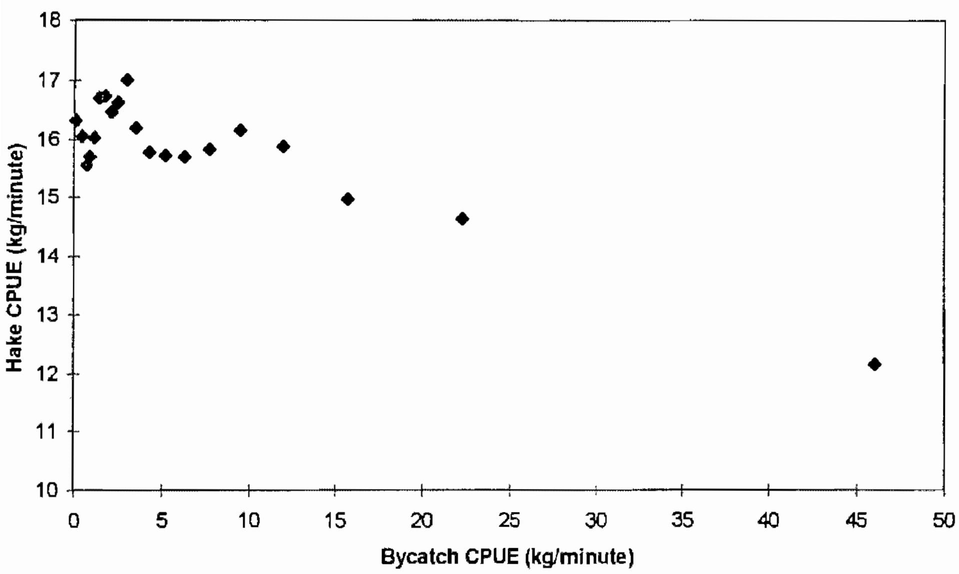


FIGURE 16 : South Coast standardised hake CPUE series.

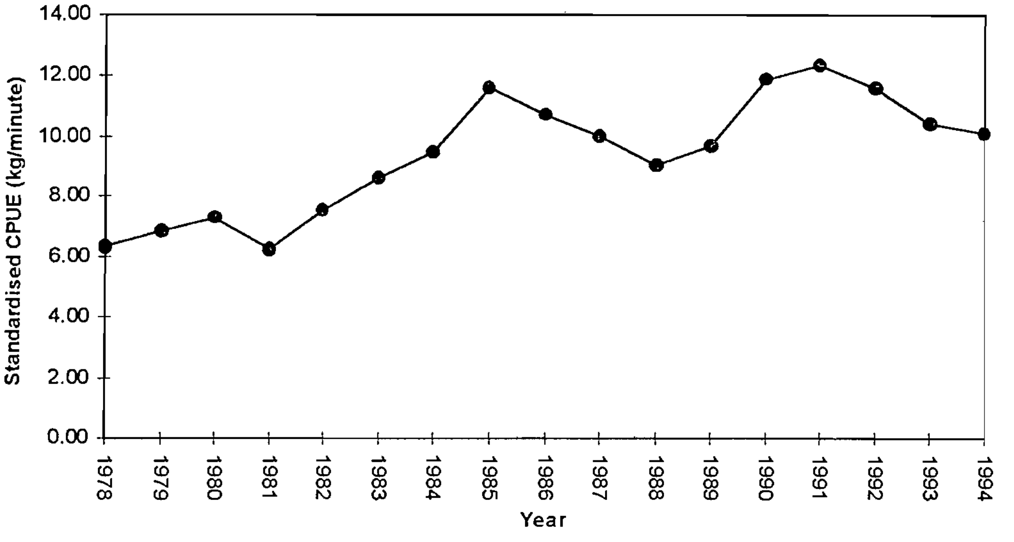


FIGURE 17 : South Coast standardised small hake CPUE series.

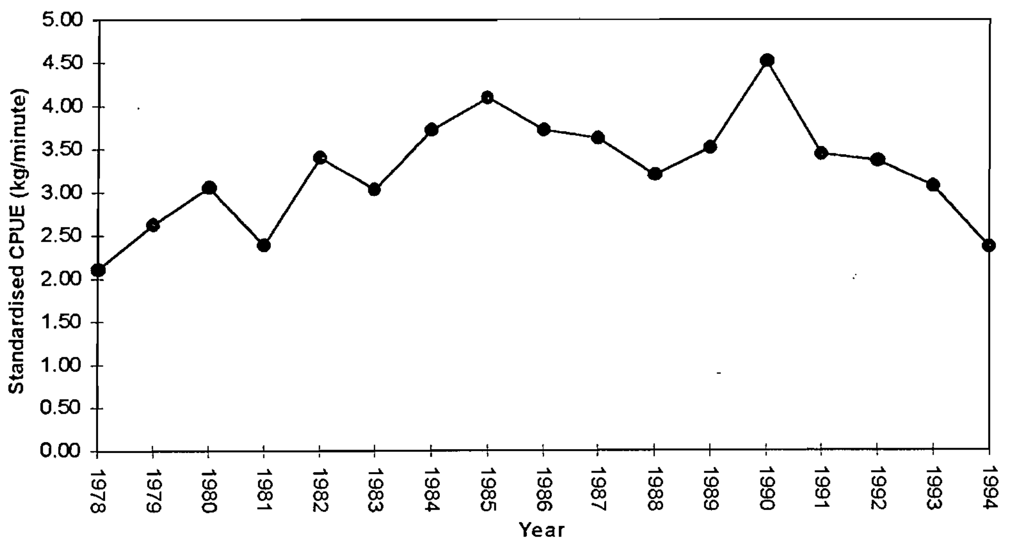


FIGURE 18 : South Coast standardised medium+large hake CPUE series.

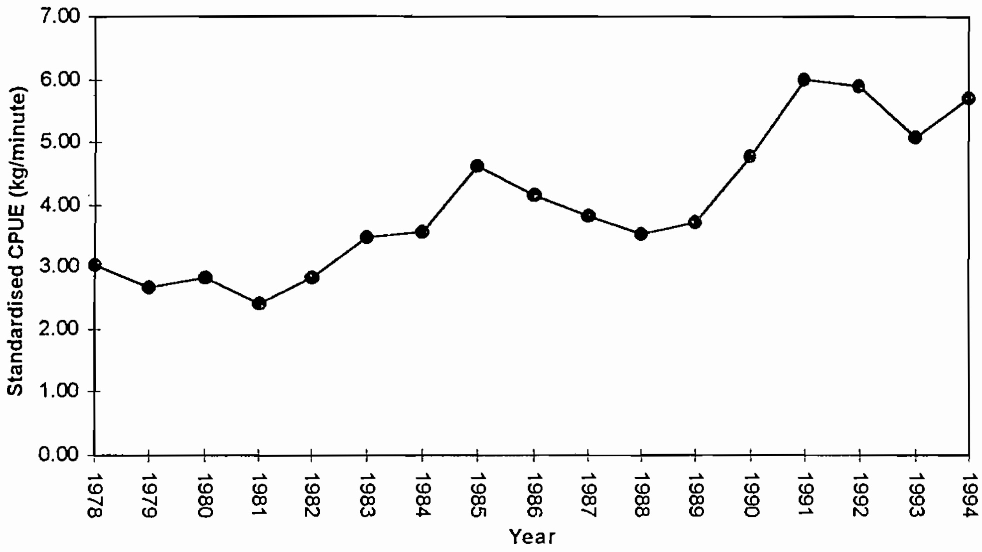


FIGURE 19: Effective average power of the West Coast fleet.

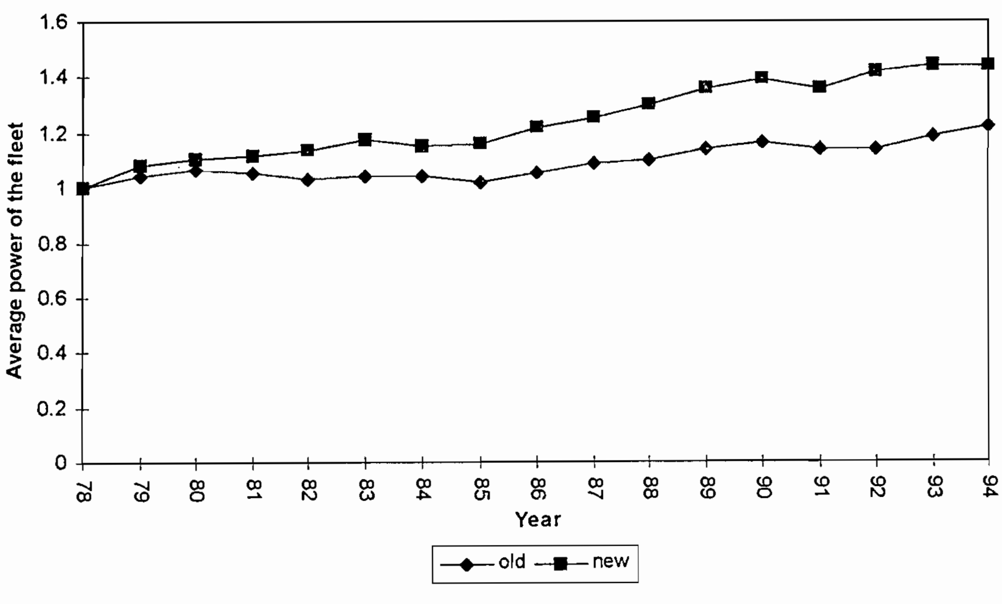


FIGURE 20: Relative density of hake on the West Coast at various depth intervals over a number of sub-periods.

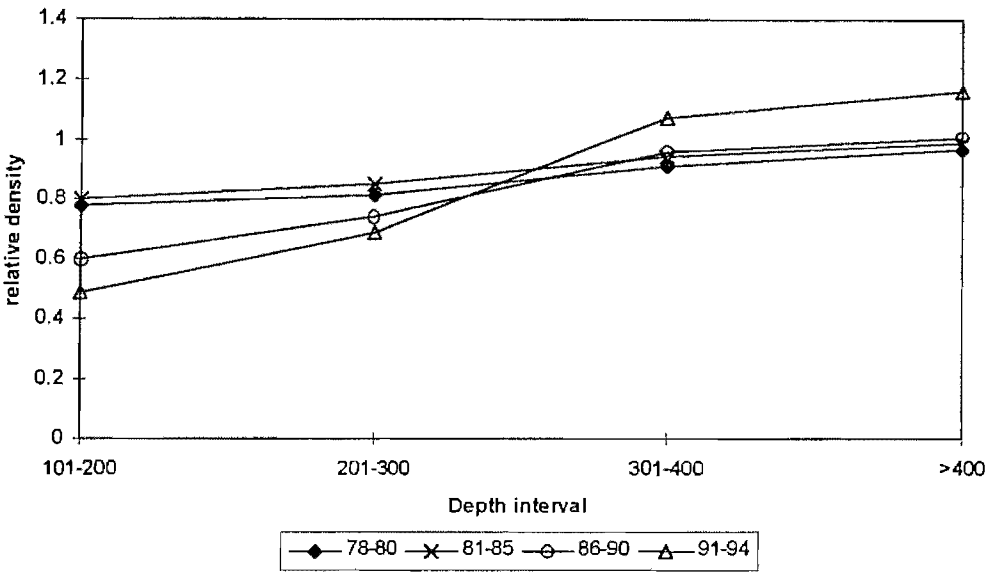


FIGURE 21: The hake caught in the 201 - 300m depth range as a proportion of the total catch in the 201 - 500m depth range, on the West Coast.

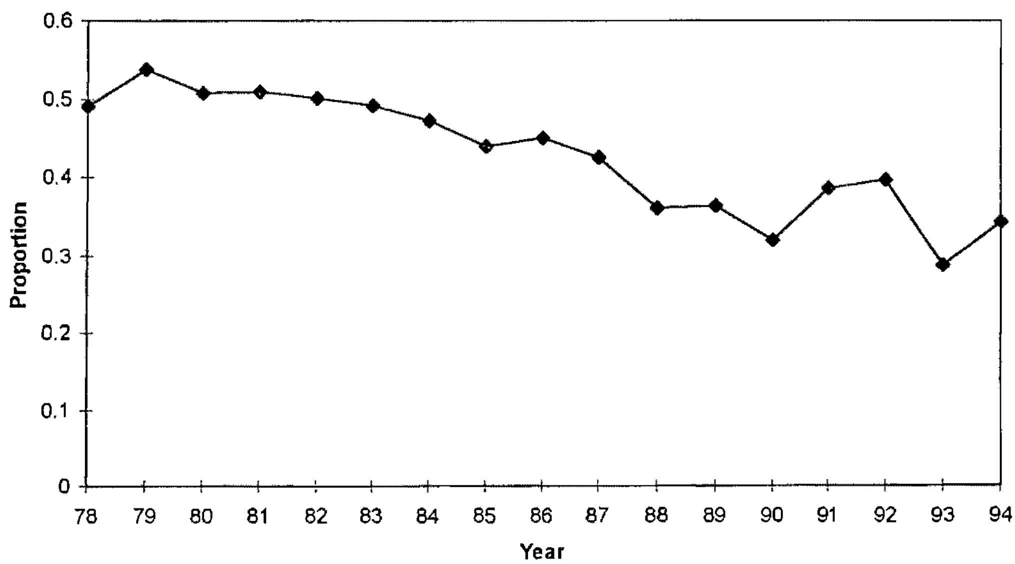


FIGURE 22 : Winter survey biomass estimates for the West Coast hake resource.

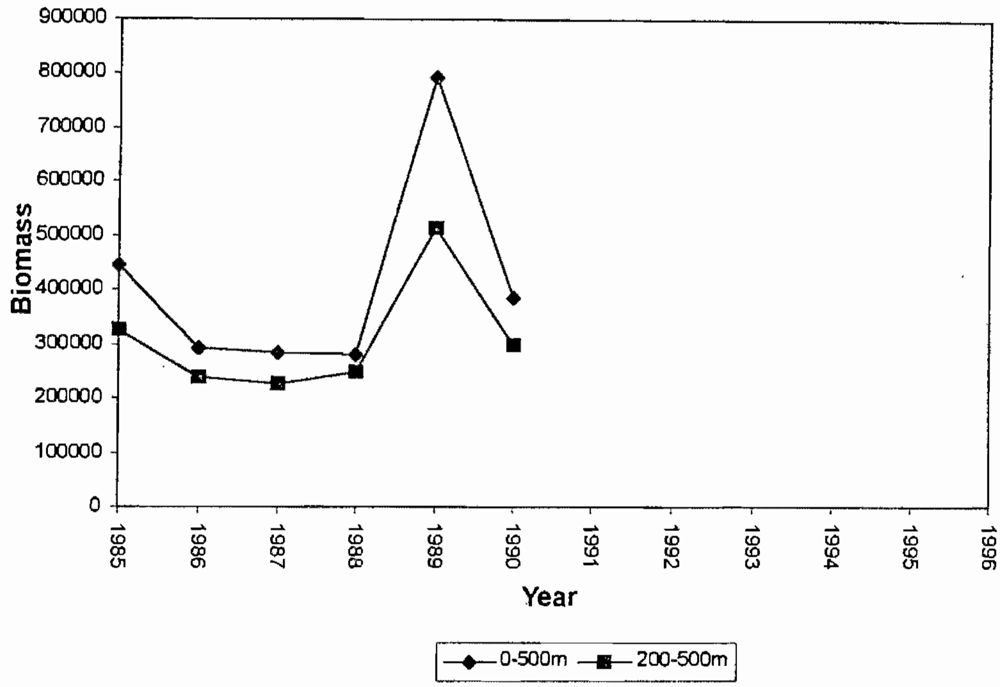


FIGURE 23 : Summer survey biomass estimates for the West Coast hake resource.

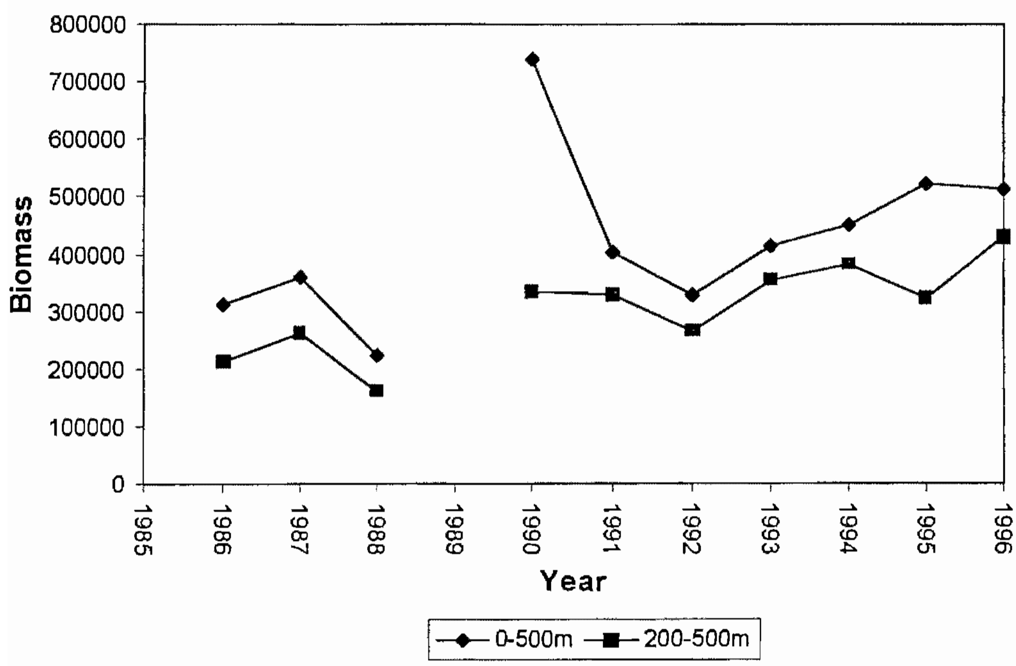


FIGURE 24 : Age-structured production model fits to the West Coast hake CPUE and survey biomass series (Source : Anon, 1997a).

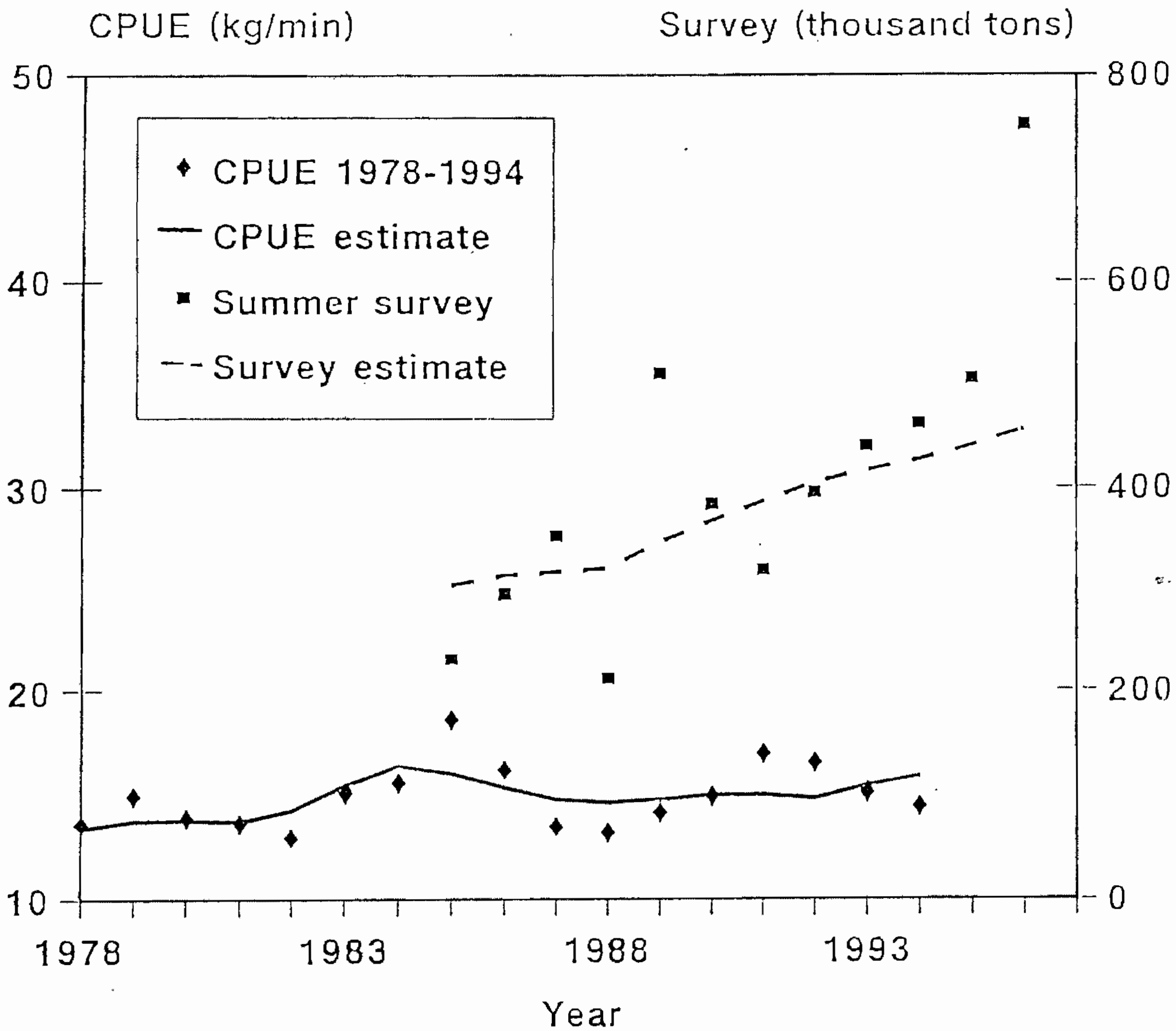


FIGURE 25 : Standard deviation of residuals for base case (5) vs effort (in 50 minute intervals).

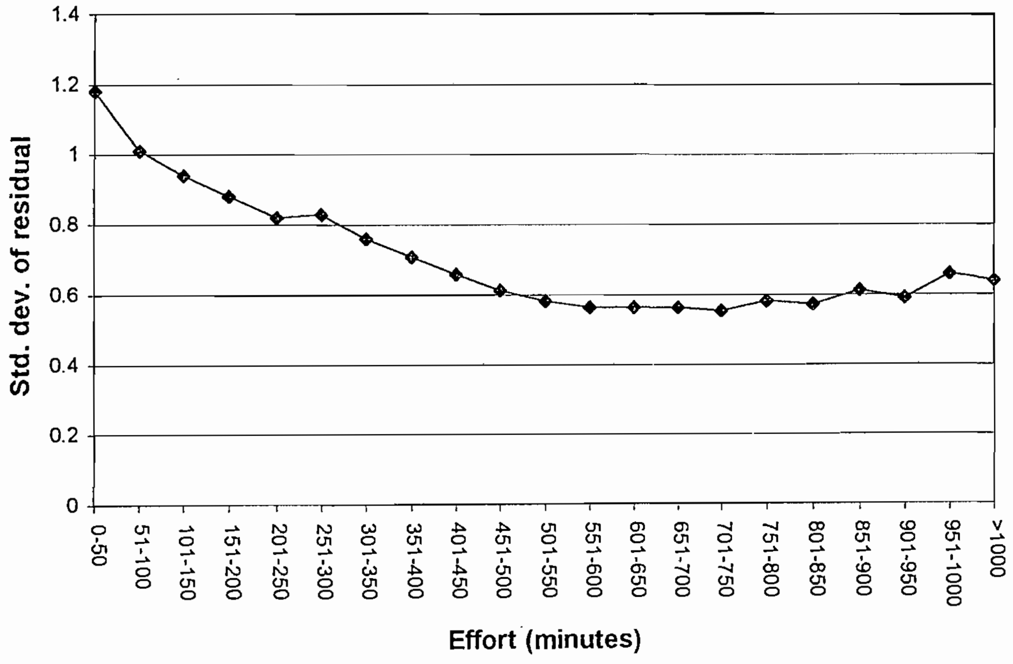


FIGURE 26 : The fishing grounds for the South Coast Rock Lobster, *Palinurus gilchristi*.

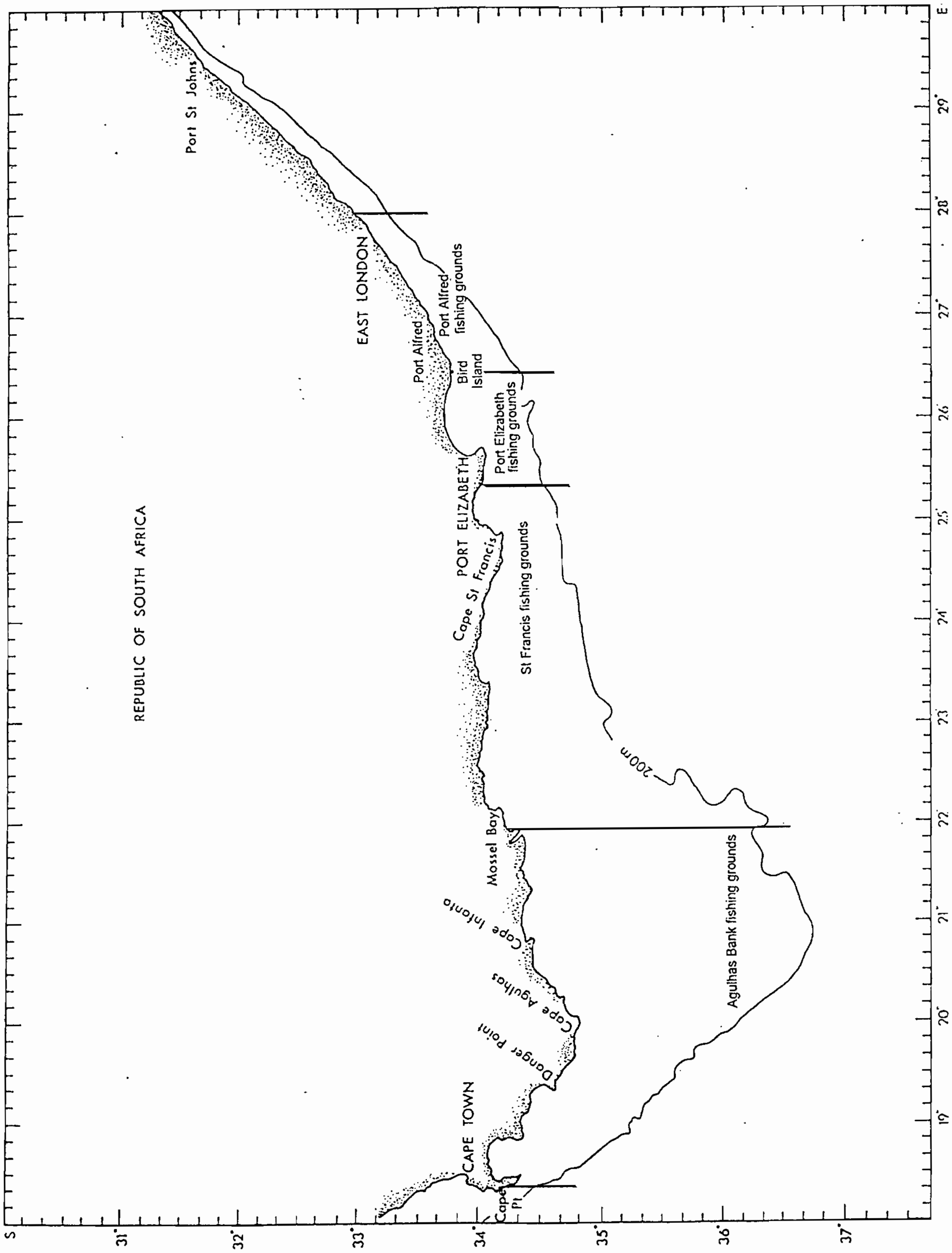


Figure 27 : South Coast rock lobster : Standard deviation of residuals vs effort (# traps)

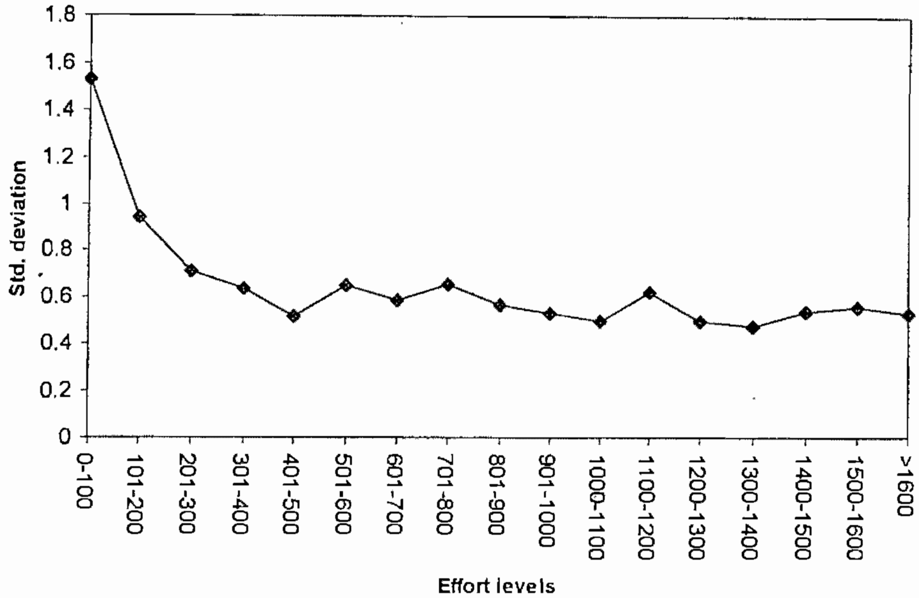


FIGURE 28 : South Coast rock lobster standardised CPUE for a model which incudes a) a company (C) effect and b) a vessel (V) effect, where weight $w = 1/\sigma^2$.

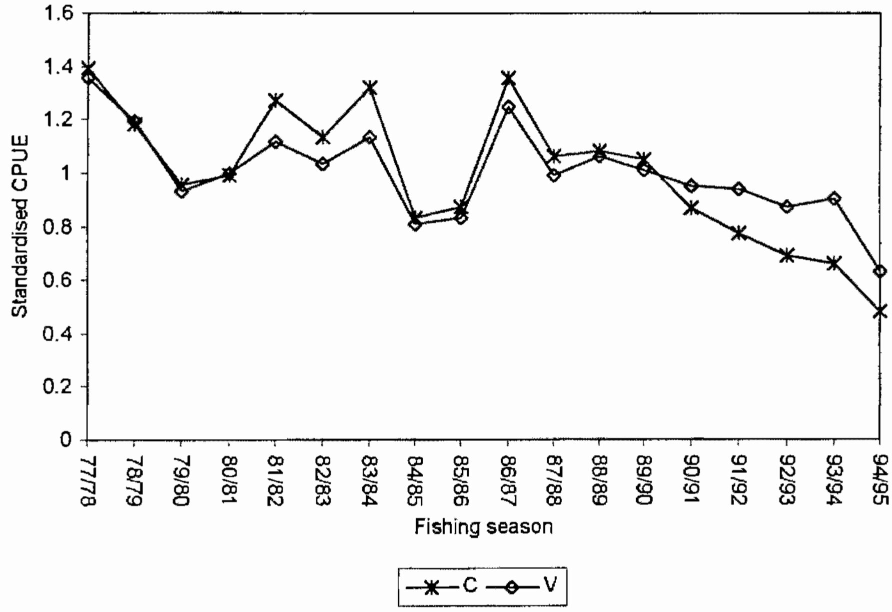


FIGURE 29 : South coast rock lobster standardised CPUE derived from the 1997 iterative effort weighted GLM.

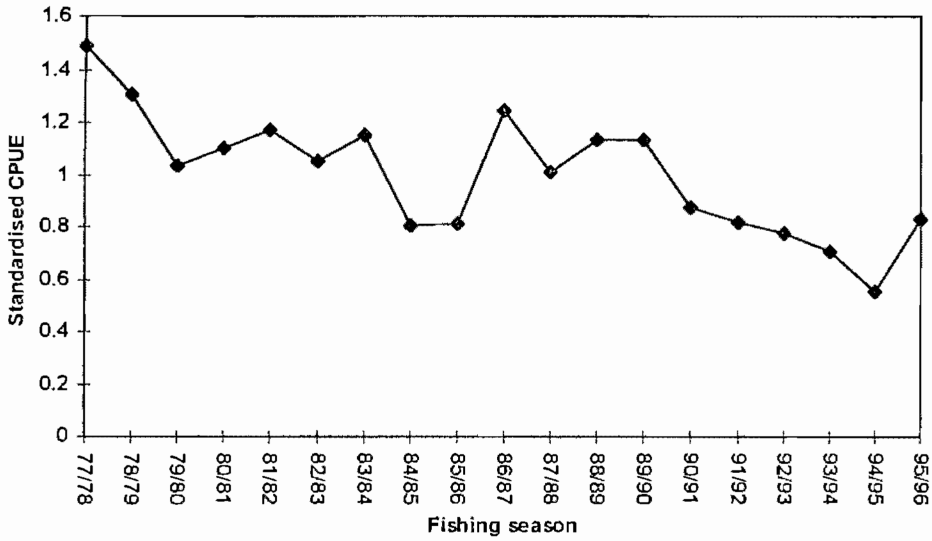


FIGURE 30 : South coast rock lobster standardised CPUE for a model which includes a) a "month" effect and b) a "season" effect.

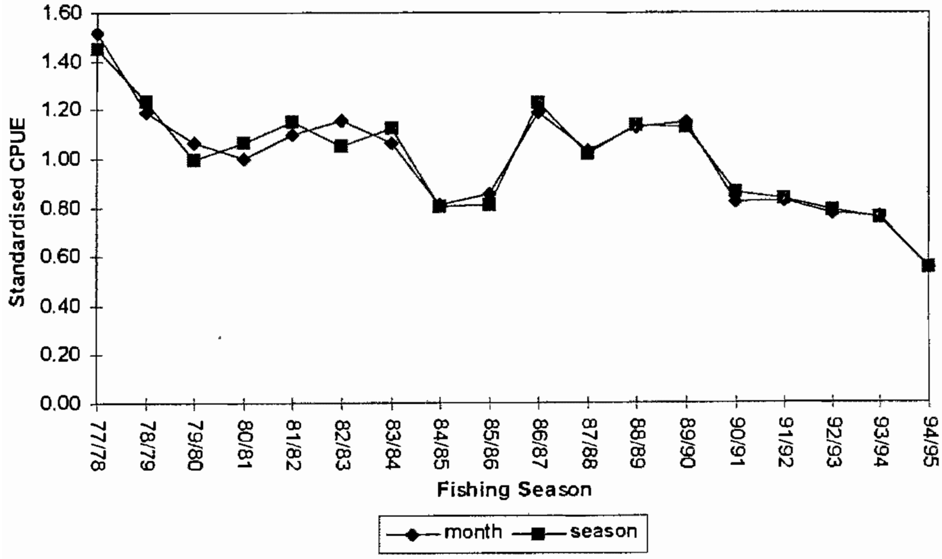


FIGURE 31 : South coast rock lobster standardised CPUE where season 4 (July - September) is a) included and b) excluded from the CPUE calculation.

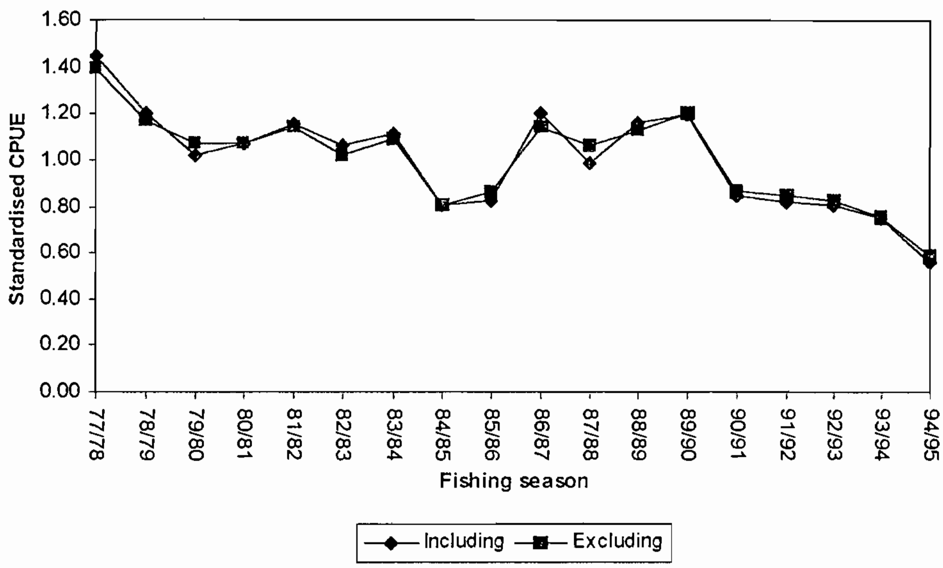


FIGURE 32 : South coast rock lobster standardised CPUE obtained from a) a zone-based and b) a grid-based GLM.

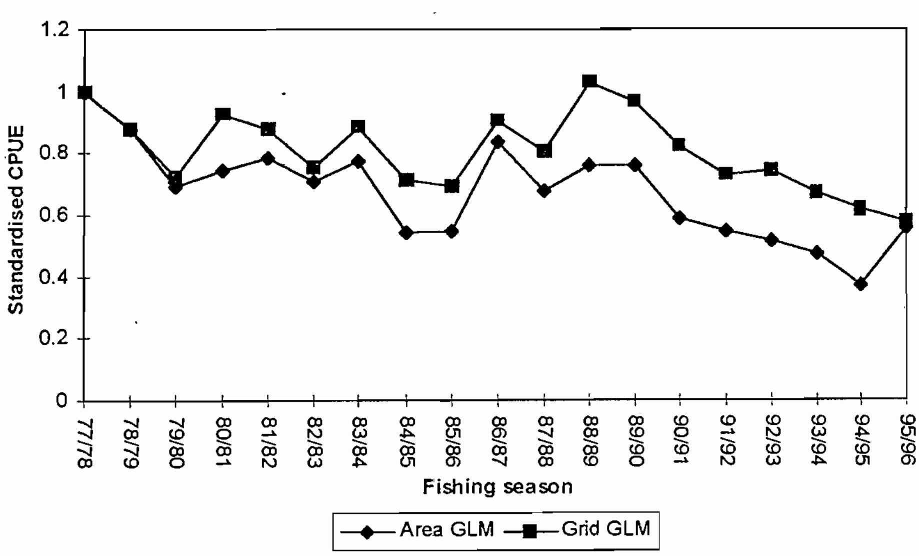


FIGURE 33 : South Coast rock lobster standardised CPUE for a model which a) includes and b) excludes the trap (effort) covariate.

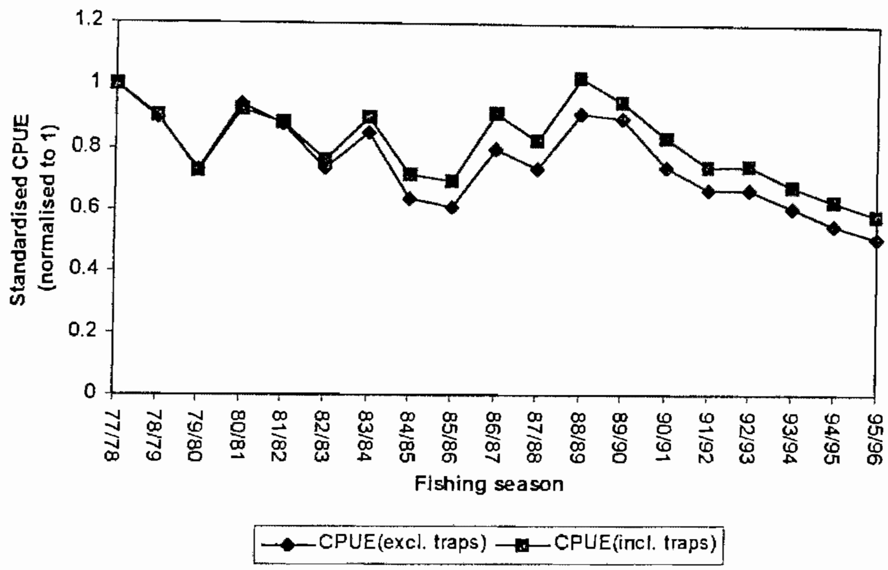


FIGURE 34 : Average number of traps used per set for each fishing season in the south coast rock lobster fishery.

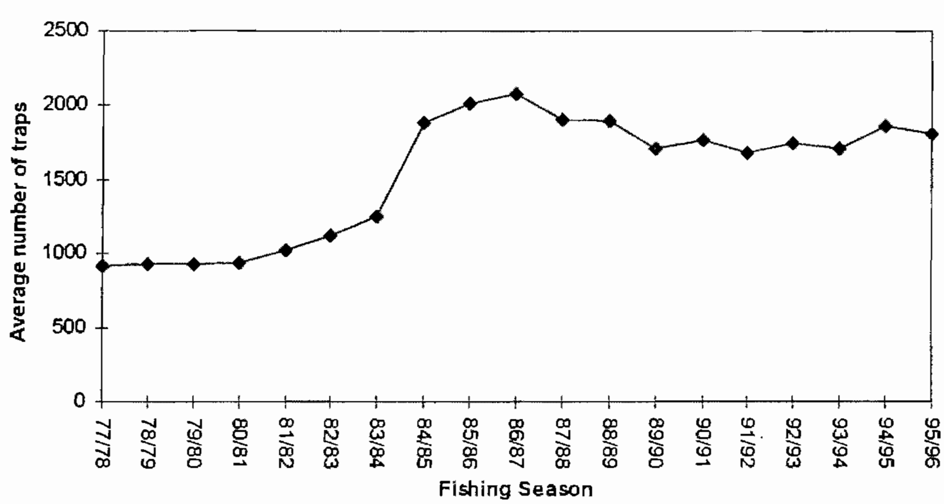


FIGURE 35 : West Coast rock lobster catches for the period 1870 - 1997.

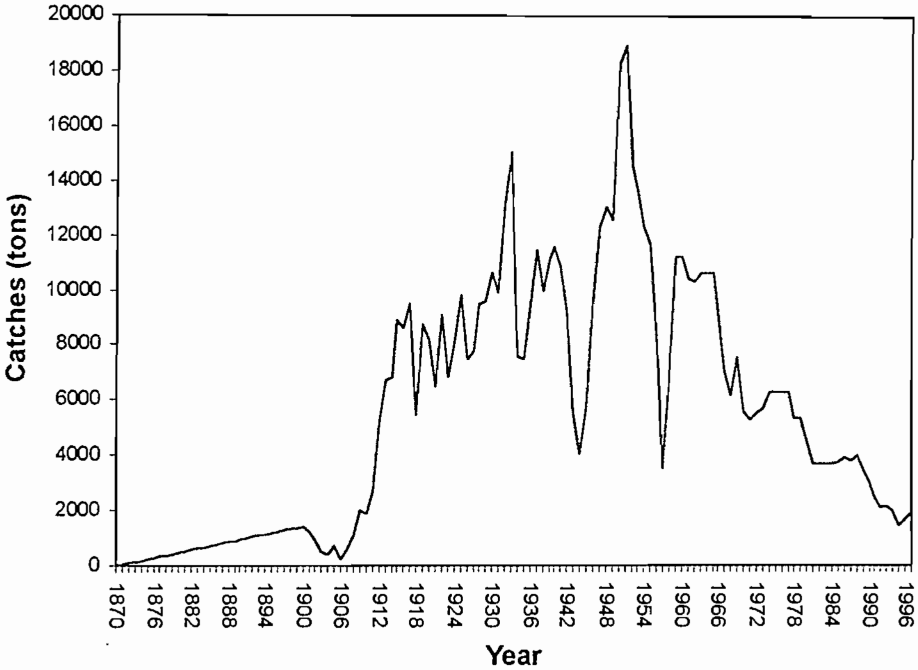


FIGURE 36 : The South African fishing areas defined for the West Coast Rock Lobster, *Jasus lalandii*.

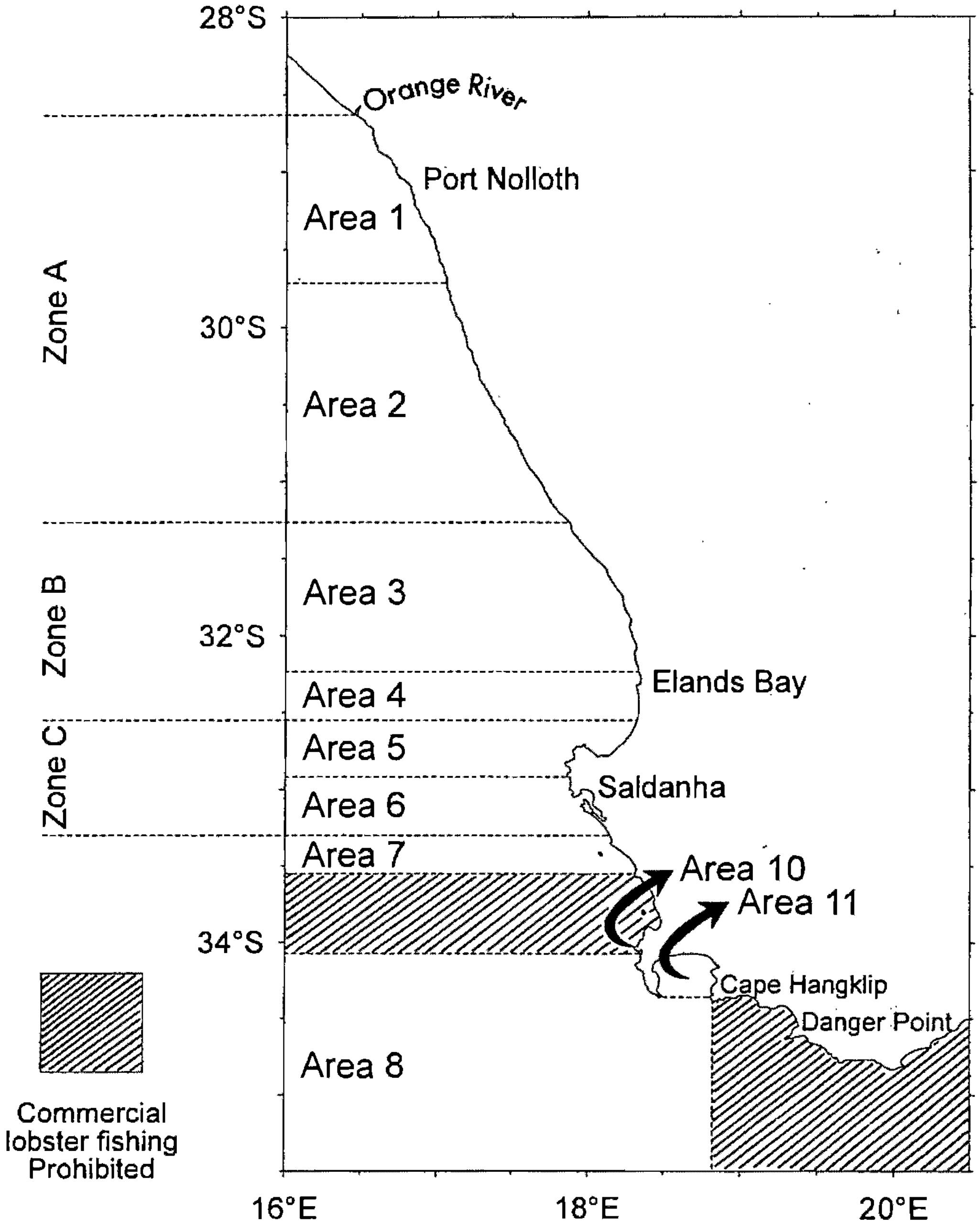


FIGURE 37 : Standardised CPUE derived from west coast rock lobster deckboat and bakkie data.

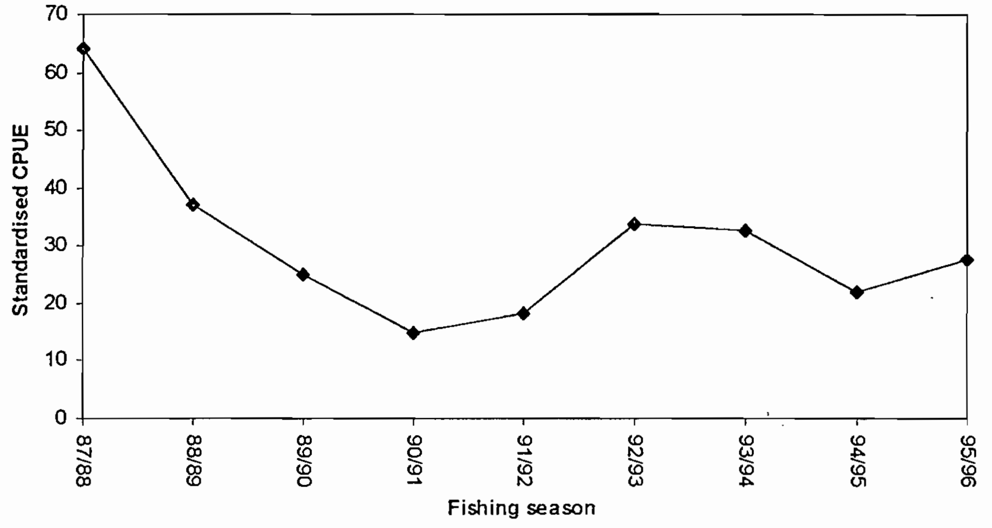
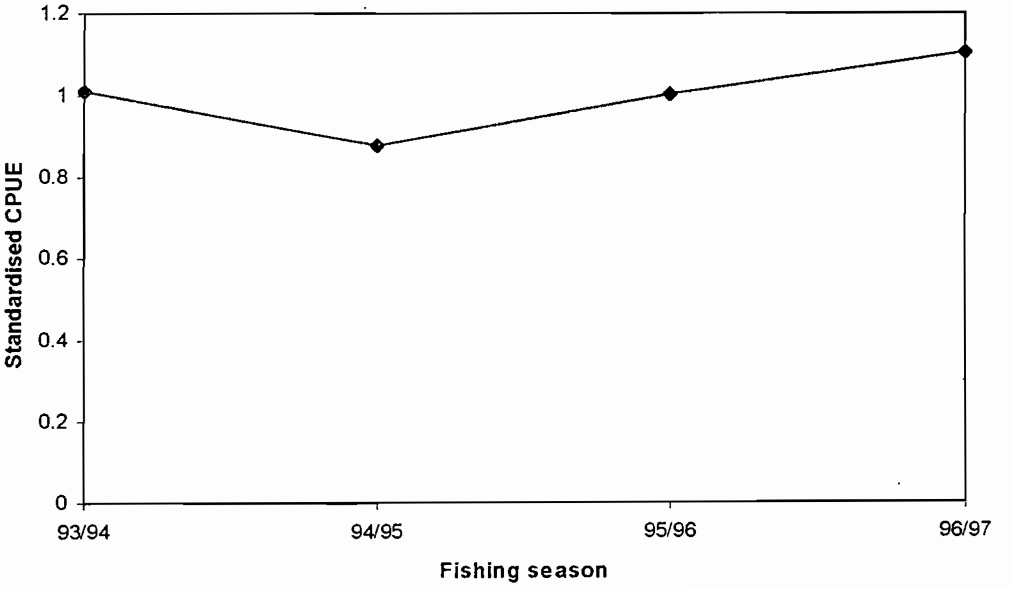


FIGURE 38 : Standardised CPUE for west coast rock lobster derived from a GLM applied to trap, deck-boat and bakkie data.



APPENDICES

APPENDIX A

This Appendix details the various manners in which the skippers in the demersal fishery record catches for the drags carried out over a day.

Example 1 : Drag-by-drag reporting (total catch = 550kg):

Date	Drag Number	Target Species	Hake Catch (kg)	Effort (minutes)
02/05/89	1	H	190	50
02/05/89	2	M	10	25
02/05/89	3	H	350	100

where H refers to hake and M to horse-mackerel.

Example 2 : Daily reporting (total catch = 550kg):

Date	Drag Number	Target Species	Hake Catch (kg)	Effort (minutes)
02/05/89	1	H		50
02/05/89	2	M		25
02/05/89	3	H	550	100

Example 3 : Drag-by-drag reporting with the catch averaged across the drags (total catch = 360kg):

Date	Drag Number	Target Species	Hake Catch (kg)	Effort (minutes)
02/05/89	1	H	120	50
02/05/89	2	M	120	25
02/05/89	3	H	120	100

Example 4 : Drag-by-drag reporting with the catch averaged across the drags, but with rounding error (total catch = 500kg):

Date	Drag Number	Target Species	Hake Catch (kg)	Effort (minutes)
02/05/89	1	H	166	50
02/05/89	2	M	166	25
02/05/89	3	H	168	100

Example 1 is the ideal situation, but frequent use of the methods of reporting catches illustrated in examples 2 - 4 have made it necessary to accumulate the data over a day for each vessel before GLM analyses can be conducted.

APPENDIX B

For the process of generating a simulated data set to test the validity of the method proposed for correcting for the positive correlation evident between hake and bycatch CPUE, a distribution to reflect the actual bycatch CPUE was required. From this distribution a random number x^+ was drawn to provide a specific "observation". This Appendix details the method used to develop this distribution and the selection criteria applied for accepting or rejecting the random number drawn.

The observed bycatch rates for each year were re-normalised so that their means were all 1:

$$x^+_{y,i} = \frac{x_{y,i}}{\frac{1}{n_y} * \sum_i x_{y,i}}$$

where : $x_{y,i}$ is the i^{th} bycatch CPUE observed in year y, and

n_y is the sample size in year y.

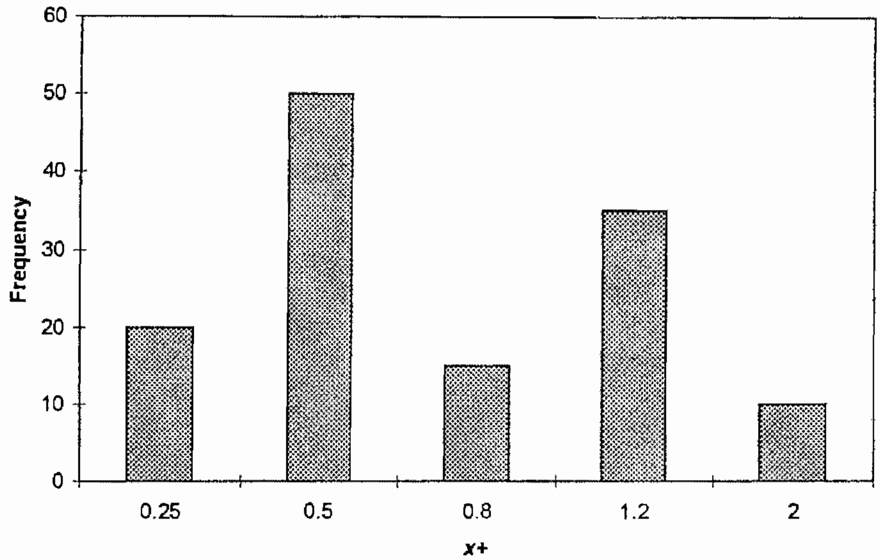
The $x^+_{y,i}$ values were rounded at the third decimal place to yield a finite number of possible values of x^+ between 0 and x^+_{max}. $x^+_{y,i}$ will henceforth be referred to as x^+ since they will no longer be used in a year dependent context, i.e. it is assumed that the x^+ distribution is year-independent.

The following method was then used to generate random x^+ values corresponding to the empirical probability distribution.

The frequency of occurrence of the x^+ values was determined, allowing for the generation of a frequency distribution. The frequencies of occurrence were then normalised to a maximum of 1 by dividing each frequency of occurrence by the largest frequency of occurrence. As an example, assume that there are 5 x^+ values and associated frequencies of occurrence as follows:

x^{+}	Frequency
0.25	20
0.5	50
0.8	15
1.2	35
2.0($=x_{max}$)	10

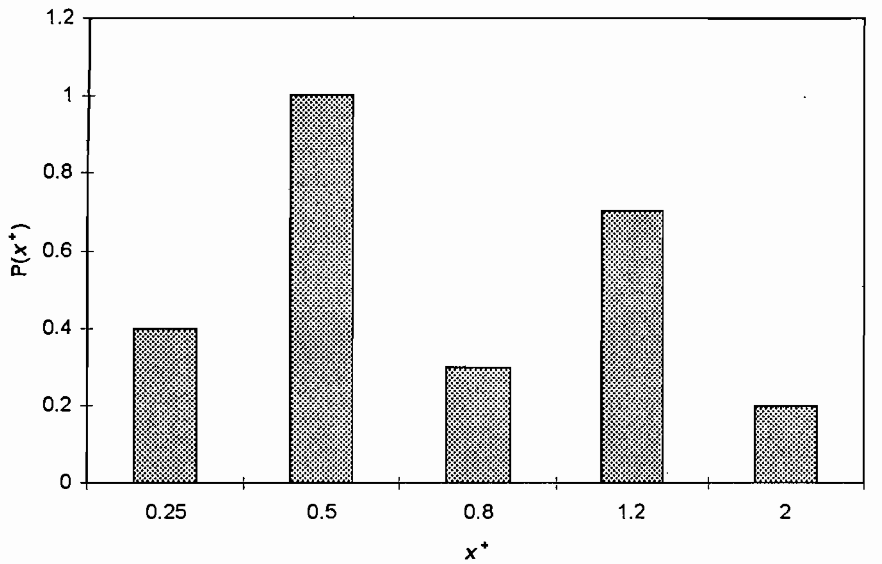
These would translate into a frequency distribution as follows:



Since the largest frequency of occurrence is 50, each frequency of occurrence is divided by 50 to yield relative frequencies of occurrence normalised to a maximum of 1:

x^{+}	Frequency
0.25	20/50 = 0.4
0.5	50/50 = 1.0
0.8	15/50 = 0.3
1.2	35/50 = 0.7
2.0($=x_{max}$)	10/50 = 0.1

The preceding plot is therefore translated into the following:



Random x^+ is then generated from $U[\ 0\ , x_{max}^+\ ]$ and Φ is generated from $U[\ 0\ , 1\ ]$. These would then correspond to some x^+ and $P(x^+)$ values in the above distribution. The random value x^+ is accepted if $\Phi < P(x^+)$, otherwise new x^+ and Φ values are generated until $\Phi < P(x^+)$.

Linear interpolation was used to generate $P(x^+)$ values for all those x^+ values which occurred between 0 and x_{max}^+, but which were not represented by the actual data.

APPENDIX C

Appendix 5 of Anon (1996a) is reproduced here, but with bluefin replaced by hake.

ADJUSTING FOR TARGETING ON OTHER SPECIES IN GLM'S

C_h = hake catch

C_o = other species catch

E_h = hake directed effort

E_o = other species directed effort

Nominal effort = E_h+E_o

How does measured hake catch rate C_h/E relate to hake abundance B_h where

$$\frac{C_h}{E_h} = q_h B_h$$

Consider the case where $E_o << E_h$

$$\frac{C_h}{E} = \frac{C_h}{E_h} * \frac{E_h}{E_h+E_o} \approx q_h B_h (1 - \frac{E_o}{E_h})$$

Now

$$\frac{C_o}{E} = \frac{C_o}{E_o} * \frac{E_o}{E} = q_o B_o \frac{E_o}{E_h+E_o} \approx q_o B_o \frac{E_o}{E_h}$$

Thus

$$\frac{E_o}{E_h} \approx \frac{1}{q_o B_o} \frac{C_o}{E}$$

i.e.

$$\frac{C_h}{E} \approx q_h B_h (1 - \frac{1}{q_o B_o} \frac{C_o}{E})$$

or

$$ln\frac{C_h}{E} \approx lnq_h B_h - \frac{1}{q_o B_o}\frac{C_o}{E}$$

Therefore, if we use a linear model for log catch rate of the species of interest with the catch rate of other species as an explanatory variable, the associated implicit assumptions are:

1) the true abundance (B_o) of the other species is constant in time (or at least has no temporal trend), and

2) the proportion of the total effort targeted on the other species is small.

```
data drags;

infile 'k:\user\jglazer\hake\wcoast';
     input  compcode  1 - 3
            boatcode  4 - 6
            landyear  12 - 13
            dragmnth  20 - 21
            effort   24 - 29
            depth    30 - 33
            hakectch  37 - 46
            hmack    47 - 56
            monk     57 - 66
            kklip    67 - 76
            ecsole   77 - 86
            wcsole   87 - 96
            snoek    97 - 106
            mack     107 - 116
            wsquid   117 - 126
            rsquid   127 - 136
            undecl   197 - 206
            latitude  208 - 211
            target $ 218 - 219
      ;
decl = hmack + monk + kklip + ecsole + wcsole + snoek +
mack + wsquid + rsquid;

totcat = hakectch + decl + undecl;

if (effort > 0) and (totcat = 0) then delete;

if target NE 'H' then delete;

if effort > 1090 then delete;

  cpue = hakectch/effort;
  bycatch = decl/effort;

  lat = latitude + 17;

if (landyear = 78) and (cpue > 54.29) then delete;
if (landyear = 79) and (cpue > 70.77) then delete;
if (landyear = 80) and (cpue > 58.09) then delete;
 if (landyear = 81) and (cpue > 56.59) then delete;
 if (landyear = 82) and (cpue > 70.44) then delete;
 if (landyear = 83) and (cpue > 64.75) then delete;
 if (landyear = 84) and (cpue > 81.59) then delete;
if (landyear = 85) and (cpue > 82.00) then delete;
if (landyear = 86) and (cpue > 98.37) then delete;
 if (landyear = 87) and (cpue > 75.79) then delete;
 if (landyear = 88) and (cpue > 91.56) then delete;
 if (landyear = 89) and (cpue > 84.65) then delete;
if (landyear = 90) and (cpue >113.58) then delete;
if (landyear = 91) and (cpue >106.83) then delete;
if (landyear = 92) and (cpue > 93.98) then delete;
if (landyear = 93) and (cpue >106.87) then delete;
if (landyear = 94) and (cpue >156.63) then delete;

if (landyear = 78) and (bycatch > 20.52) then delete;
if (landyear = 79) and (bycatch > 30.45) then delete;
if (landyear = 80) and (bycatch > 20.98) then delete;
 if (landyear = 81) and (bycatch > 16.83) then delete;
if (landyear = 82) and (bycatch > 12.54) then delete;
```



```
if (landyear = 83) and (bycatch > 17.52) then delete;
if (landyear = 84) and (bycatch > 20.81) then delete;
if (landyear = 85) and (bycatch > 22.57) then delete;
if (landyear = 86) and (bycatch > 25.42) then delete;
if (landyear = 87) and (bycatch > 29.43) then delete;
if (landyear = 88) and (bycatch > 47.72) then delete;
if (landyear = 89) and (bycatch > 37.33) then delete;
if (landyear = 90) and (bycatch > 43.58) then delete;
if (landyear = 91) and (bycatch > 52.36) then delete;
if (landyear = 92) and (bycatch > 47.88) then delete;
if (landyear = 93) and (bycatch > 56.76) then delete;
if (landyear = 94) and (bycatch > 31.05) then delete;

if ((boatcode = 9) or (boatcode = 21) or (boatcode = 158) or
(boatcode = 196) or (boatcode = 200) or (boatcode = 208) or
(boatcode = 209) or (boatcode = 241) or (boatcode = 249) or
(boatcode = 263) or (boatcode = 264) or (boatcode = 274) or
(boatcode = 276) or (boatcode = 280)) then delete;

proc means data = drags noprint mean;
 var cpue;
  output out=meancpue mean =    cpuemean;
run;

proc print data = meancpue;
run;
data hakdat;
 If _N_ = 1 then set meancpue;
  set drags;

     bcode1 = 0;
     bcode2 = 0;
     bcode3 = 0;
     bcode4 = 0;
     bcode5 = 0;
     bcode6 = 0;
     bcode7 = 0;
     bcode8 = 0;
     bcode9 = 0;
     bcode10= 0;
     bcode11= 0;
     bcode12= 0;.
     bcode13= 0;
     bcode14= 0;
     bcode15= 0;
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     bcode31= 0;
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bcode66= 0;
bcode67= 0;
bcode68= 0;
bcode69= 0;
bcode70= 0;
bcode71= 0;
bcode72= 0;
bcode73= 0;
bcode74= 0;
bcode75= 0;
bcode76= 0;
bcode77= 0;
bcode78= 0;
bcode79= 0;
bcode80= 0;
bcode81= 0;
bcode82= 0;
bcode83= 0;
bcode84= 0;
bcode85= 0;
bcode86= 0;
bcode87= 0;
bcode88= 0;
bcode89= 0;
bcode90= 0;
bcode91= 0;
bcode92= 0;
bcode93= 0;
bcode94= 0;
```



```
bcode95= 0;
bcode96= 0;
bcode97= 0;
bcode98= 0;
bcode99= 0;
bcode100= 0;
bcode101 = 0;
bcode102 = 0;
bcode103 = 0;
bcode104 = 0;
bcode105 = 0;
bcode106 = 0;
bcode107 = 0;
bcode108 = 0;
bcode109 = 0;
bcode110 = 0;

if boatcode = 1 then bcode1 = 1;
if boatcode = 2 then bcode2 = 1;
if boatcode = 3 then bcode3 = 1;
if boatcode = 4 then bcode4 = 1;
if boatcode = 5 then bcode5 = 1;
if boatcode = 6 then bcode6 = 1;
if boatcode = 7 then bcode7 = 1;
if boatcode = 10 then bcode8 = 1;
if boatcode = 11 then bcode9 = 1;
if boatcode = 12 then bcode10= 1;
if boatcode = 14 then bcode11= 1;
if boatcode = 15 then bcode12= 1;
if boatcode = 16 then bcode13= 1;
if boatcode = 19 then bcode14= 1;
if boatcode = 20 then bcode15= 1;
if boatcode = 22 then bcode16= 1;
if boatcode = 23 then bcode17= 1;
if boatcode = 24 then bcode18= 1;
if boatcode = 25 then bcode19= 1;
if boatcode = 26 then bcode20= 1;
if boatcode = 27 then bcode21= 1;
if boatcode = 28 then bcode22= 1;
if boatcode = 29 then bcode23= 1;
if boatcode = 30 then bcode24= 1;
if boatcode = 31 then bcode25= 1;
if boatcode = 33 then bcode26= 1;
if boatcode = 34 then bcode27= 1;
if boatcode = 35 then bcode28= 1;
if boatcode = 36 then bcode29= 1;
if boatcode = 37 then bcode30= 1;
if boatcode = 38 then bcode31= 1;
if boatcode = 41 then bcode32= 1;
if boatcode = 44 then bcode33= 1;
if boatcode = 46 then bcode34= 1;
if boatcode = 49 then bcode35= 1;
if boatcode = 51 then bcode36= 1;
if boatcode = 52 then bcode37= 1;
if boatcode = 53 then bcode38= 1;
if boatcode = 54 then bcode39= 1;
if boatcode = 55 then bcode40= 1;
if boatcode = 56 then bcode41= 1;
if boatcode = 61 then bcode42= 1;
if boatcode = 62 then bcode43= 1;
if boatcode = 63 then bcode44= 1;
if boatcode = 65 then bcode45= 1;
```

```
if boatcode = 66 then bcode46= 1;
if boatcode = 70 then bcode47= 1;
if boatcode = 72 then bcode48= 1;
if boatcode = 73 then bcode49= 1;
if boatcode = 74 then bcode50= 1;
if boatcode = 75 then bcode51= 1;
if boatcode = 76 then bcode52= 1;
if boatcode = 77 then bcode53= 1;
if boatcode = 78 then bcode54= 1;
if boatcode = 79 then bcode55= 1;
if boatcode = 82 then bcode56= 1;
if boatcode = 86 then bcode57= 1;
if boatcode =115 then bcode58= 1;
if boatcode =116 then bcode59= 1;
if boatcode =144 then bcode60= 1;
if boatcode =148 then bcode61= 1;
if boatcode = 149 then bcode62= 1;
if boatcode = 150 then bcode63= 1;
if boatcode = 155 then bcode64= 1;
if boatcode = 156 then bcode65= 1;
if boatcode = 159 then bcode66= 1;
if boatcode = 160 then bcode67= 1;
if boatcode = 161 then bcode68= 1;
if boatcode = 175 then bcode69= 1;
if boatcode = 184 then bcode70= 1;
if boatcode = 188 then bcode71= 1;
if boatcode = 189 then bcode72= 1;
if boatcode = 198 then bcode73= 1;
if boatcode = 206 then bcode74= 1;
if boatcode = 207 then bcode75= 1;
if boatcode = 210 then bcode76= 1;
if boatcode = 211 then bcode77= 1;
if boatcode = 212 then bcode78= 1;
if boatcode = 213 then bcode79= 1;
if boatcode = 214 then bcode80= 1;
if boatcode = 215 then bcode81= 1;
if boatcode = 219 then bcode82= 1;
if boatcode = 220 then bcode83= 1;
if boatcode = 221 then bcode84= 1;
if boatcode = 222 then bcode85= 1;
if boatcode = 223 then bcode86= 1;
if boatcode = 224 then bcode87= 1;
if boatcode = 226 then bcode88= 1;
if boatcode = 231 then bcode89= 1;
if boatcode = 232 then bcode90= 1;
if boatcode = 233 then bcode91= 1;
if boatcode = 234 then bcode92= 1;
if boatcode = 235 then bcode93= 1;
if boatcode = 236 then bcode94= 1;
if boatcode = 238 then bcode95= 1;
if boatcode = 240 then bcode96= 1;
if boatcode = 245 then bcode97= 1;
if boatcode = 247 then bcode98= 1;
if boatcode = 248 then bcode99= 1;
if boatcode = 250 then bcode100= 1;
if boatcode = 254 then bcode101= 1;
if boatcode = 255 then bcode102= 1;
if boatcode = 256 then bcode103= 1;
if boatcode = 261 then bcode104= 1;
if boatcode = 265 then bcode105= 1;
if boatcode = 266 then bcode106= 1;
if boatcode = 267 then bcode107= 1;
```



```
if boatcode = 273 then bcode108= 1;
if boatcode = 275 then bcode109= 1;
if boatcode = 278 then bcode110= 1;

if depth <= 100 then d1 = 1;
   else d1 = 0;
if 101<= depth <= 200 then d2 = 1;
   else d2 = 0;
if 201 <= depth <= 300 then d3 = 1;
   else d3 = 0;
if 301 <= depth <= 400 then d4 = 1;
   else d4 = 0;
if depth >= 401 then d5 = 1;
   else d5 = 0;

 lat1 = 0;
 lat2 = 0;
 lat3 = 0;
 lat4 = 0;

if lat <= 3100 then lat1 = 1;
if 3100 < lat <=3300 then lat2 = 1;
if 3300 < lat <= 3433 then lat3 = 1;
if lat > 3433 then lat4 = 1;

if ((01 <= dragmnth <= 02) or (dragmnth = 12)) then summer
= 1;
   else summer = 0;
if (03 <= dragmnth <= 05) then autumn = 1;
   else autumn = 0;
if (06 <= dragmnth <= 08) then winter = 1;
   else winter = 0;
if (09 <= dragmnth <= 11) then spring = 1;
   else spring = 0;

 year78 = 0;
 year79 = 0;
 year80 = 0;
 year81 = 0;
 year82 = 0;
 year83 = 0;
 year84 = 0;
 year85 = 0;
 year86 = 0;
 year87 = 0;
 year88 = 0;
 year89 = 0;
 year90 = 0;
 year91 = 0;
 year92 = 0;
 year93 = 0;
 year94 = 0;

  if landyear = 78 then year78 = 1;
  if landyear = 79 then year79 = 1;
  if landyear = 80 then year80 = 1;
  if landyear = 81 then year81 = 1;
  if landyear = 82 then year82 = 1;
  if landyear = 83 then year83 = 1;
  if landyear = 84 then year84 = 1;
  if landyear = 85 then year85 = 1;
  if landyear = 86 then year86 = 1;
```

```
    if landyear = 87 then year87 = 1;
    if landyear = 88 then year88 = 1;
    if landyear = 89 then year89 = 1;
    if landyear = 90 then year90 = 1;
    if landyear = 91 then year91 = 1;
    if landyear = 92 then year92 = 1;
    if landyear = 93 then year93 = 1;
    if landyear = 94 then year94 = 1;

    delta = 0.10*cpuemean;
    lncpue = log(cpue+delta);
    bycat2 = bycatch**2;


proc glm;
model lncpue=year79 year80 year81 year82 year83 year84
year85 year86 year87 year88 year89 year90 year91 year92
year93 year94
d1 d2 d3 d4
lat2 lat3 lat4
 autumn winter spring
bcode2 bcode3 bcode4 bcode5 bcode6 bcode7 bcode8
bcode9 bcode10 bcode11 bcode12 bcode13 bcode14
bcode15 bcode16 bcode17 bcode18 bcode19 bcode20
bcode21 bcode22 bcode23 bcode24 bcode25 bcode26
bcode27 bcode28 bcode29 bcode30 bcode31 bcode32
bcode33 bcode34 bcode35 bcode36 bcode37 bcode38
bcode39 bcode40 bcode41 bcode42 bcode43 bcode44
bcode45 bcode46 bcode47 bcode48 bcode49 bcode50
bcode51 bcode52 bcode53 bcode54 bcode55 bcode56
bcode57 bcode58 bcode59 bcode60 bcode61 bcode62
bcode63 bcode64 bcode65 bcode66 bcode67 bcode68
bcode69 bcode70 bcode71 bcode72 bcode73 bcode74
bcode75 bcode76 bcode77 bcode78 bcode79 bcode80
bcode81 bcode82 bcode83 bcode84 bcode85 bcode86
bcode87 bcode88 bcode89 bcode90 bcode91 bcode92
bcode93 bcode94 bcode95 bcode96 bcode97 bcode98
bcode99 bcode100 bcode101 bcode102 bcode103 bcode104
bcode105 bcode106 bcode107 bcode108 bcode109
bcode110
bycatch
bycat2
year79*d1 year79*d2 year79*d3 year79*d4
year80*d1 year80*d2 year80*d3 year80*d4
year81*d1 year81*d2 year81*d3 year81*d4
year82*d1 year82*d2 year82*d3 year82*d4
year83*d1 year83*d2 year83*d3 year83*d4
year84*d1 year84*d2 year84*d3 year84*d4
year85*d1 year85*d2 year85*d3 year85*d4
year86*d1 year86*d2 year86*d3 year86*d4
year87*d1 year87*d2 year87*d3 year87*d4
year88*d1 year88*d2 year88*d3 year88*d4
year89*d1 year89*d2 year89*d3 year89*d4
year90*d1 year90*d2 year90*d3 year90*d4
year91*d1 year91*d2 year91*d3 year91*d4
year92*d1 year92*d2 year92*d3 year92*d4
year93*d1 year93*d2 year93*d3 year93*d4
year94*d1 year94*d2 year94*d3 year94*d4
year79*lat2 year79*lat3 year79*lat4
year80*lat2 year80*lat3 year80*lat4
year81*lat2 year81*lat3 year81*lat4
year82*lat2 year82*lat3 year82*lat4
```



```
year83*lat2 year83*lat3 year83*lat4
year84*lat2 year84*lat3 year84*lat4
year85*lat2 year85*lat3 year85*lat4
year86*lat2 year86*lat3 year86*lat4
year87*lat2 year87*lat3 year87*lat4
year88*lat2 year88*lat3 year88*lat4
year89*lat2 year89*lat3 year89*lat4
year90*lat2 year90*lat3 year90*lat4
year91*lat2 year91*lat3 year91*lat4
year92*lat2 year92*lat3 year92*lat4
year93*lat2 year93*lat3 year93*lat4
year94*lat2 year94*lat3 year94*lat4
d1*lat2 d1*lat3 d1*lat4
d2*lat2 d2*lat3 d2*lat4
d3*lat2 d3*lat3 d3*lat4
d4*lat2 d4*lat3 d4*lat4
  ;
 output out = resout r = resid;
 run;

proc univariate data = resout plot normal;
   var resid;
 run;
```

OBS	_TYPE_	_FREQ_	CPUEMEAN
1	0	136702	19.5206

General Linear Models Procedure

Number of observations in data set = 136702

General Linear Models Procedure

Dependent Variable: LNCPUE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	255	23368.64145765	91.64173121	224.26	0.0001
Error	136446	55758.45438689	0.40864851		
Corrected Total	136701	79127.09584453			

R-Square	C.V.	Root MSE	LNCPUE Mean
0.295330	22.79546	0.63925622	2.80431406

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR79	1	165.85854300	165.85854300	405.87	0.0001
YEAR80	1	547.82277120	547.82277120	1340.57	0.0001
YEAR81	1	358.26481147	358.26481147	876.71	0.0001
YEAR82	1	756.15253431	756.15253431	1850.37	0.0001
YEAR83	1	122.37379405	122.37379405	299.46	0.0001
YEAR84	1	57.99913514	57.99913514	141.93	0.0001
YEAR85	1	1.74880984	1.74880984	4.28	0.0386
YEAR86	1	8.87723535	8.87723535	21.72	0.0001
YEAR87	1	332.18026566	332.18026566	812.88	0.0001
YEAR88	1	132.44549797	132.44549797	324.11	0.0001
YEAR89	1	70.49001098	70.49001098	172.50	0.0001
YEAR90	1	33.27959212	33.27959212	81.44	0.0001
YEAR91	1	42.85691978	42.85691978	104.87	0.0001
YEAR92	1	38.45939612	38.45939612	94.11	0.0001
YEAR93	1	231.21136173	231.21136173	565.80	0.0001
YEAR94	1	1396.82372590	1396.82372590	3418.15	0.0001
D1	1	1.26066342	1.26066342	3.08	0.0790
D2	1	317.95743820	317.95743820	778.07	0.0001
D3	1	3011.98615331	3011.98615331	7370.60	0.0001
D4	1	487.08938855	487.08938855	1191.95	0.0001
LAT2	1	391.94576152	391.94576152	959.13	0.0001
LAT3	1	593.73382111	593.73382111	1452.92	0.0001
LAT4	1	434.04621894	434.04621894	1062.15	0.0001
AUTUMN	1	369.63230969	369.63230969	904.52	0.0001
WINTER	1	106.85617318	106.85617318	261.49	0.0001
SPRING	1	235.95322290	235.95322290	577.40	0.0001
BCODE2	1	26.72255974	26.72255974	65.39	0.0001
BCODE3	1	37.72159737	37.72159737	92.31	0.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BCODE4	1	57.18662979	57.18662979	139.94	0.0001
BCODE5	1	3.02152336	3.02152336	7.39	0.0065
BCODE6	1	27.28797952	27.28797952	66.78	0.0001
BCODE7	1	19.06648116	19.06648116	46.66	0.0001
BCODE8	1	200.40492330	200.40492330	490.41	0.0001
BCODE9	1	228.08712928	228.08712928	558.15	0.0001
BCODE10	1	54.43064273	54.43064273	133.20	0.0001
BCODE11	1	7.89749471	7.89749471	19.33	0.0001
BCODE12	1	240.18332246	240.18332246	587.75	0.0001
BCODE13	1	186.24573379	186.24573379	455.76	0.0001
BCODE14	1	18.55857762	18.55857762	45.41	0.0001
BCODE15	1	49.75937036	49.75937036	121.77	0.0001
BCODE16	1	106.70472263	106.70472263	261.12	0.0001
BCODE17	1	164.52013240	164.52013240	402.60	0.0001
BCODE18	1	123.13005529	123.13005529	301.31	0.0001
BCODE19	1	153.20018324	153.20018324	374.89	0.0001
BCODE20	1	110.44994807	110.44994807	270.28	0.0001
BCODE21	1	191.33770256	191.33770256	468.22	0.0001
BCODE22	1	164.15698619	164.15698619	401.71	0.0001
BCODE23	1	198.32840194	198.32840194	485.33	0.0001
BCODE24	1	266.63894712	266.63894712	652.49	0.0001
BCODE25	1	32.74888377	32.74888377	80.14	0.0001
BCODE26	1	602.23072780	602.23072780	1473.71	0.0001
BCODE27	1	118.14536283	118.14536283	289.10	0.0001
BCODE28	1	2.53492062	2.53492062	6.20	0.0128
BCODE29	1	25.06399474	25.06399474	61.33	0.0001
BCODE30	1	19.73213993	19.73213993	48.29	0.0001
BCODE31	1	22.77583468	22.77583468	55.73	0.0001
BCODE32	1	3.45608045	3.45608045	8.46	0.0036
BCODE33	1	7.79199971	7.79199971	19.07	0.0001
BCODE34	1	1.23203535	1.23203535	3.01	0.0825
BCODE35	1	0.19642903	0.19642903	0.48	0.4881
BCODE36	1	11.59623237	11.59623237	28.38	0.0001
BCODE37	1	128.07260015	128.07260015	313.41	0.0001
BCODE38	1	34.76874077	34.76874077	85.08	0.0001
BCODE39	1	97.74362797	97.74362797	239.19	0.0001
BCODE40	1	22.65363402	22.65363402	55.44	0.0001
BCODE41	1	6.53472722	6.53472722	15.99	0.0001
BCODE42	1	76.55540644	76.55540644	187.34	0.0001
BCODE43	1	121.98735985	121.98735985	298.51	0.0001
BCODE44	1	7.56115270	7.56115270	18.50	0.0001
BCODE45	1	102.64287354	102.64287354	251.18	0.0001
BCODE46	1	0.25704042	0.25704042	0.63	0.4277
BCODE47	1	16.72880465	16.72880465	40.94	0.0001
BCODE48	1	39.72157867	39.72157867	97.20	0.0001
BCODE49	1	73.67538608	73.67538608	180.29	0.0001
BCODE50	1	22.75776493	22.75776493	55.69	0.0001
BCODE51	1	138.85410265	138.85410265	339.79	0.0001
BCODE52	1	63.02919818	63.02919818	154.24	0.0001
BCODE53	1	95.32004905	95.32004905	233.26	0.0001
BCODE54	1	133.30843906	133.30843906	326.22	0.0001
BCODE55	1	0.82366178	0.82366178	2.02	0.1557
BCODE56	1	157.18399140	157.18399140	384.64	0.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BCODE57	1	657.79521323	657.79521323	1609.68	0.0001
BCODE58	1	16.43551743	16.43551743	40.22	0.0001
BCODE59	1	2.58957915	2.58957915	6.34	0.0118
BCODE60	1	29.07700650	29.07700650	71.15	0.0001
BCODE61	1	74.84820511	74.84820511	183.16	0.0001
BCODE62	1	123.63225042	123.63225042	302.54	0.0001
BCODE63	1	178.41468301	178.41468301	436.60	0.0001
BCODE64	1	0.88588284	0.88588284	2.17	0.1409
BCODE65	1	19.88141868	19.88141868	48.65	0.0001
BCODE66	1	181.18367030	181.18367030	443.37	0.0001
BCODE67	1	218.72894619	218.72894619	535.25	0.0001
BCODE68	1	4.27175060	4.27175060	10.45	0.0012
BCODE69	1	173.89450886	173.89450886	425.54	0.0001
BCODE70	1	63.76648919	63.76648919	156.04	0.0001
BCODE71	1	95.59303935	95.59303935	233.92	0.0001
BCODE72	1	0.43237682	0.43237682	1.06	0.3037
BCODE73	1	37.43573980	37.43573980	91.61	0.0001
BCODE74	1	7.40675943	7.40675943	18.13	0.0001
BCODE75	1	9.62155252	9.62155252	23.54	0.0001
BCODE76	1	272.43642528	272.43642528	666.68	0.0001
BCODE77	1	81.12816649	81.12816649	198.53	0.0001
BCODE78	1	24.96797766	24.96797766	61.10	0.0001
BCODE79	1	125.51596463	125.51596463	307.15	0.0001
BCODE80	1	36.48596578	36.48596578	89.28	0.0001
BCODE81	1	28.62321052	28.62321052	70.04	0.0001
BCODE82	1	31.02242813	31.02242813	75.91	0.0001
BCODE83	1	120.10579346	120.10579346	293.91	0.0001
BCODE84	1	131.97526159	131.97526159	322.96	0.0001
BCODE85	1	42.95609003	42.95609003	105.12	0.0001
BCODE86	1	1057.12472447	1057.12472447	2586.88	0.0001
BCODE87	1	2.14378741	2.14378741	5.25	0.0220
BCODE88	1	623.69898256	623.69898256	1526.25	0.0001
BCODE89	1	20.34153760	20.34153760	49.78	0.0001
BCODE90	1	23.26967425	23.26967425	56.94	0.0001
BCODE91	1	47.32368942	47.32368942	115.81	0.0001
BCODE92	1	6.49277760	6.49277760	15.89	0.0001
BCODE93	1	46.32673489	46.32673489	113.37	0.0001
BCODE94	1	73.05432017	73.05432017	178.77	0.0001
BCODE95	1	3.18273190	3.18273190	7.79	0.0053
BCODE96	1	321.83704072	321.83704072	787.56	0.0001
BCODE97	1	146.66613019	146.66613019	358.91	0.0001
BCODE98	1	18.35300705	18.35300705	44.91	0.0001
BCODE99	1	1.82090181	1.82090181	4.46	0.0348
BCODE100	1	37.62147342	37.62147342	92.06	0.0001
BCODE101	1	272.13373996	272.13373996	665.94	0.0001
BCODE102	1	26.97862711	26.97862711	66.02	0.0001
BCODE103	1	31.06561674	31.06561674	76.02	0.0001
BCODE104	1	132.18103376	132.18103376	323.46	0.0001
BCODE105	1	1.00674356	1.00674356	2.46	0.1165
BCODE106	1	15.89173712	15.89173712	38.89	0.0001
BCODE107	1	13.85973075	13.85973075	33.92	0.0001
BCODE108	1	18.73616824	18.73616824	45.85	0.0001
BCODE109	1	12.21861897	12.21861897	29.90	0.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BCODE110	1	48.72887422	48.72887422	119.24	0.0001
BYCATCH	1	796.42841961	796.42841961	1948.93	0.0001
BYCAT2	1	102.75313553	102.75313553	251.45	0.0001
YEAR79*D1	1	0.32837618	0.32837618	0.80	0.3700
YEAR79*D2	1	0.69733357	0.69733357	1.71	0.1915
YEAR79*D3	1	50.95249922	50.95249922	124.69	0.0001
YEAR79*D4	1	0.63932735	0.63932735	1.56	0.2110
YEAR80*D1	0	0.00000000	.	.	.
YEAR80*D2	1	3.43150061	3.43150061	8.40	0.0038
YEAR80*D3	1	10.26496342	10.26496342	25.12	0.0001
YEAR80*D4	1	1.59570705	1.59570705	3.90	0.0481
YEAR81*D1	1	0.59993884	0.59993884	1.47	0.2256
YEAR81*D2	1	14.96024179	14.96024179	36.61	0.0001
YEAR81*D3	1	51.57069759	51.57069759	126.20	0.0001
YEAR81*D4	1	12.13519860	12.13519860	29.70	0.0001
YEAR82*D1	1	0.08402866	0.08402866	0.21	0.6502
YEAR82*D2	1	1.29412700	1.29412700	3.17	0.0751
YEAR82*D3	1	69.08505063	69.08505063	169.06	0.0001
YEAR82*D4	1	1.48718294	1.48718294	3.64	0.0564
YEAR83*D1	0	0.00000000	.	.	.
YEAR83*D2	1	5.72461349	5.72461349	14.01	0.0002
YEAR83*D3	1	13.99336058	13.99336058	34.24	0.0001
YEAR83*D4	1	1.07379815	1.07379815	2.63	0.1050
YEAR84*D1	1	6.34337783	6.34337783	15.52	0.0001
YEAR84*D2	1	9.50161873	9.50161873	23.25	0.0001
YEAR84*D3	1	58.60420384	58.60420384	143.41	0.0001
YEAR84*D4	1	0.29141310	0.29141310	0.71	0.3984
YEAR85*D1	1	0.00088872	0.00088872	0.00	0.9628
YEAR85*D2	1	2.91600365	2.91600365	7.14	0.0076
YEAR85*D3	1	16.77342796	16.77342796	41.05	0.0001
YEAR85*D4	1	1.87589943	1.87589943	4.59	0.0322
YEAR86*D1	1	0.02652994	0.02652994	0.06	0.7989
YEAR86*D2	1	10.48200296	10.48200296	25.65	0.0001
YEAR86*D3	1	76.86567698	76.86567698	188.10	0.0001
YEAR86*D4	1	8.63440289	8.63440289	21.13	0.0001
YEAR87*D1	1	0.05500803	0.05500803	0.13	0.7137
YEAR87*D2	1	4.45496233	4.45496233	10.90	0.0010
YEAR87*D3	1	37.95797526	37.95797526	92.89	0.0001
YEAR87*D4	1	0.16825009	0.16825009	0.41	0.5211
YEAR88*D1	1	4.85139002	4.85139002	11.87	0.0006
YEAR88*D2	1	2.47551399	2.47551399	6.06	0.0138
YEAR88*D3	1	68.13666372	68.13666372	166.74	0.0001
YEAR88*D4	1	10.17512652	10.17512652	24.90	0.0001
YEAR89*D1	0	0.00000000	.	.	.
YEAR89*D2	1	0.43930089	0.43930089	1.08	0.2998
YEAR89*D3	1	4.80303982	4.80303982	11.75	0.0006
YEAR89*D4	1	1.35437742	1.35437742	3.31	0.0687
YEAR90*D1	1	0.28852445	0.28852445	0.71	0.4008
YEAR90*D2	1	22.75468758	22.75468758	55.68	0.0001
YEAR90*D3	1	18.95083595	18.95083595	46.37	0.0001
YEAR90*D4	1	0.67016191	0.67016191	1.64	0.2003
YEAR91*D1	1	0.16745635	0.16745635	0.41	0.5221
YEAR91*D2	1	1.13814626	1.13814626	2.79	0.0951

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR91*D3	1	24.61024832	24.61024832	60.22	0.0001
YEAR91*D4	1	13.36031296	13.36031296	32.69	0.0001
YEAR92*D1	0	0.00000000	.	.	.
YEAR92*D2	1	3.76333363	3.76333363	9.21	0.0024
YEAR92*D3	1	8.59815319	8.59815319	21.04	0.0001
YEAR92*D4	1	0.00005490	0.00005490	0.00	0.9908
YEAR93*D1	1	0.00188548	0.00188548	0.00	0.9458
YEAR93*D2	1	2.51163085	2.51163085	6.15	0.0132
YEAR93*D3	1	23.20707372	23.20707372	56.79	0.0001
YEAR93*D4	1	18.14525935	18.14525935	44.40	0.0001
YEAR94*D1	0	0.00000000	.	.	.
YEAR94*D2	1	19.27274019	19.27274019	47.16	0.0001
YEAR94*D3	1	58.17379320	58.17379320	142.36	0.0001
YEAR94*D4	1	8.96916829	8.96916829	21.95	0.0001
YEAR79*LAT2	1	43.83990186	43.83990186	107.28	0.0001
YEAR79*LAT3	1	9.06292186	9.06292186	22.18	0.0001
YEAR79*LAT4	1	0.02820630	0.02820630	0.07	0.7928
YEAR80*LAT2	1	2.58386176	2.58386176	6.32	0.0119
YEAR80*LAT3	1	1.25627202	1.25627202	3.07	0.0795
YEAR80*LAT4	1	7.61738913	7.61738913	18.64	0.0001
YEAR81*LAT2	1	9.54717980	9.54717980	23.36	0.0001
YEAR81*LAT3	1	0.93545320	0.93545320	2.29	0.1303
YEAR81*LAT4	1	1.51280291	1.51280291	3.70	0.0544
YEAR82*LAT2	1	5.86836112	5.86836112	14.36	0.0002
YEAR82*LAT3	1	17.31874138	17.31874138	42.38	0.0001
YEAR82*LAT4	1	26.80229524	26.80229524	65.59	0.0001
YEAR83*LAT2	1	28.48762802	28.48762802	69.71	0.0001
YEAR83*LAT3	1	32.41729573	32.41729573	79.33	0.0001
YEAR83*LAT4	1	30.65690595	30.65690595	75.02	0.0001
YEAR84*LAT2	1	0.05257561	0.05257561	0.13	0.7198
YEAR84*LAT3	1	2.97672608	2.97672608	7.28	0.0070
YEAR84*LAT4	1	0.02096097	0.02096097	0.05	0.8208
YEAR85*LAT2	1	10.16263583	10.16263583	24.87	0.0001
YEAR85*LAT3	1	0.34466189	0.34466189	0.84	0.3584
YEAR85*LAT4	1	6.58824331	6.58824331	16.12	0.0001
YEAR86*LAT2	1	0.45700298	0.45700298	1.12	0.2903
YEAR86*LAT3	1	0.03315616	0.03315616	0.08	0.7758
YEAR86*LAT4	1	4.12645169	4.12645169	10.10	0.0015
YEAR87*LAT2	1	15.32462563	15.32462563	37.50	0.0001
YEAR87*LAT3	1	25.93161373	25.93161373	63.46	0.0001
YEAR87*LAT4	1	10.54045825	10.54045825	25.79	0.0001
YEAR88*LAT2	1	48.05824869	48.05824869	117.60	0.0001
YEAR88*LAT3	1	4.95521201	4.95521201	12.13	0.0005
YEAR88*LAT4	1	68.84972874	68.84972874	168.48	0.0001
YEAR89*LAT2	1	0.64755298	0.64755298	1.58	0.2081
YEAR89*LAT3	1	13.73799593	13.73799593	33.62	0.0001
YEAR89*LAT4	1	47.73235652	47.73235652	116.81	0.0001
YEAR90*LAT2	1	0.42800290	0.42800290	1.05	0.3061
YEAR90*LAT3	1	0.19433575	0.19433575	0.48	0.4904
YEAR90*LAT4	1	47.00675046	47.00675046	115.03	0.0001
YEAR91*LAT2	1	3.81434666	3.81434666	9.33	0.0022
YEAR91*LAT3	1	24.48766337	24.48766337	59.92	0.0001
YEAR91*LAT4	1	1.31189505	1.31189505	3.21	0.0732

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR92*LAT2	1	2.17583095	2.17583095	5.32	0.0210
YEAR92*LAT3	1	51.88872796	51.88872796	126.98	0.0001
YEAR92*LAT4	1	0.20886442	0.20886442	0.51	0.4747
YEAR93*LAT2	1	0.19149448	0.19149448	0.47	0.4936
YEAR93*LAT3	1	9.82544000	9.82544000	24.04	0.0001
YEAR93*LAT4	1	23.15761208	23.15761208	56.67	0.0001
YEAR94*LAT2	1	2.78338700	2.78338700	6.81	0.0091
YEAR94*LAT3	1	0.50383842	0.50383842	1.23	0.2668
YEAR94*LAT4	1	1.54103628	1.54103628	3.77	0.0521
D1*LAT2	0	0.00000000	.	.	.
D1*LAT3	1	1.24361752	1.24361752	3.04	0.0811
D1*LAT4	1	2.55530085	2.55530085	6.25	0.0124
D2*LAT2	1	1.79521003	1.79521003	4.39	0.0361
D2*LAT3	1	0.86642549	0.86642549	2.12	0.1454
D2*LAT4	1	0.03049072	0.03049072	0.07	0.7847
D3*LAT2	1	4.26309897	4.26309897	10.43	0.0012
D3*LAT3	1	42.90225784	42.90225784	104.99	0.0001
D3*LAT4	1	4.80340792	4.80340792	11.75	0.0006
D4*LAT2	1	50.49574173	50.49574173	123.57	0.0001
D4*LAT3	1	5.94797482	5.94797482	14.56	0.0001
D4*LAT4	1	51.67160348	51.67160348	126.45	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR79	1	9.23928001	9.23928001	22.61	0.0001
YEAR80	1	0.80599976	0.80599976	1.97	0.1602
YEAR81	1	3.86498219	3.86498219	9.46	0.0021
YEAR82	1	0.20673186	0.20673186	0.51	0.4769
YEAR83	1	4.16724033	4.16724033	10.20	0.0014
YEAR84	1	4.24560034	4.24560034	10.39	0.0013
YEAR85	1	13.71464419	13.71464419	33.56	0.0001
YEAR86	1	3.23110922	3.23110922	7.91	0.0049
YEAR87	1	0.60259873	0.60259873	1.47	0.2246
YEAR88	1	5.68883427	5.68883427	13.92	0.0002
YEAR89	1	0.70894548	0.70894548	1.73	0.1878
YEAR90	1	1.56569187	1.56569187	3.83	0.0503
YEAR91	1	39.77239334	39.77239334	97.33	0.0001
YEAR92	1	24.90019157	24.90019157	60.93	0.0001
YEAR93	1	28.94800273	28.94800273	70.84	0.0001
YEAR94	1	1.53323442	1.53323442	3.75	0.0527
D1	1	0.28996942	0.28996942	0.71	0.3996
D2	1	12.33235131	12.33235131	30.18	0.0001
D3	1	91.48695547	91.48695547	223.88	0.0001
D4	1	26.30190031	26.30190031	64.36	0.0001
LAT2	1	7.25883100	7.25883100	17.76	0.0001
LAT3	1	1.56874409	1.56874409	3.84	0.0501
LAT4	1	0.83398455	0.83398455	2.04	0.1531
AUTUMN	1	93.19926189	293.19926189	717.49	0.0001
WINTER	1	203.84503865	203.84503865	498.83	0.0001
SPRING	1	141.21312630	141.21312630	345.56	0.0001
BCODE2	1	0.00002157	0.00002157	0.00	0.9942
BCODE3	1	0.28659363	0.28659363	0.70	0.4023
BCODE4	1	197.06503437	197.06503437	482.24	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BCODE5	1	47.92495284	47.92495284	117.28	0.0001
BCODE6	1	124.79137650	124.79137650	305.38	0.0001
BCODE7	1	0.00393655	0.00393655	0.01	0.9218
BCODE8	1	353.32663294	353.32663294	864.62	0.0001
BCODE9	1	340.88330427	340.88330427	834.17	0.0001
BCODE10	1	0.04843731	0.04843731	0.12	0.7306
BCODE11	1	5.73396188	5.73396188	14.03	0.0002
BCODE12	1	356.02101702	356.02101702	871.22	0.0001
BCODE13	1	320.70282962	320.70282962	784.79	0.0001
BCODE14	1	82.20516506	82.20516506	201.16	0.0001
BCODE15	1	0.01217387	0.01217387	0.03	0.8630
BCODE16	1	234.45188782	234.45188782	573.73	0.0001
BCODE17	1	261.26205125	261.26205125	639.33	0.0001
BCODE18	1	224.20135008	224.20135008	548.64	0.0001
BCODE19	1	237.90311436	237.90311436	582.17	0.0001
BCODE20	1	186.45428348	186.45428348	456.27	0.0001
BCODE21	1	254.58991164	254.58991164	623.00	0.0001
BCODE22	1	14.88121799	14.88121799	36.42	0.0001
BCODE23	1	283.41215681	283.41215681	693.54	0.0001
BCODE24	1	317.53452429	317.53452429	777.04	0.0001
BCODE25	1	0.19994920	0.19994920	0.49	0.4842
BCODE26	1	496.98551325	496.98551325	1216.17	0.0001
BCODE27	1	6.54753642	6.54753642	16.02	0.0001
BCODE28	1	4.64724450	4.64724450	11.37	0.0007
BCODE29	1	0.04549852	0.04549852	0.11	0.7386
BCODE30	1	1.75683833	1.75683833	4.30	0.0381
BCODE31	1	0.01262953	0.01262953	0.03	0.8605
BCODE32	1	4.57509197	4.57509197	11.20	0.0008
BCODE33	1	5.85644601	5.85644601	14.33	0.0002
BCODE34	1	35.74637390	35.74637390	87.47	0.0001
BCODE35	1	4.94576439	4.94576439	12.10	0.0005
BCODE36	1	14.16828808	14.16828808	34.67	0.0001
BCODE37	1	16.28249587	16.28249587	39.84	0.0001
BCODE38	1	77.08172605	77.08172605	188.63	0.0001
BCODE39	1	119.68454911	119.68454911	292.88	0.0001
BCODE40	1	54.28761555	54.28761555	132.85	0.0001
BCODE41	1	5.07734247	5.07734247	12.42	0.0004
BCODE42	1	0.55561840	0.55561840	1.36	0.2436
BCODE43	1	174.13924536	174.13924536	426.13	0.0001
BCODE44	1	0.34257271	0.34257271	0.84	0.3599
BCODE45	1	127.53700373	127.53700373	312.09	0.0001
BCODE46	1	9.68469040	9.68469040	23.70	0.0001
BCODE47	1	42.18651641	42.18651641	103.23	0.0001
BCODE48	1	70.82241483	70.82241483	173.31	0.0001
BCODE49	1	94.82187776	94.82187776	232.04	0.0001
BCODE50	1	35.90978868	35.90978868	87.87	0.0001
BCODE51	1	149.48657076	149.48657076	365.81	0.0001
BCODE52	1	90.04528592	90.04528592	220.35	0.0001
BCODE53	1	97.46364063	97.46364063	238.50	0.0001
BCODE54	1	103.30020075	103.30020075	252.78	0.0001
BCODE55	1	14.59798096	14.59798096	35.72	0.0001
BCODE56	1	113.87108604	113.87108604	278.65	0.0001
BCODE57	1	421.61552474	421.61552474	1031.73	0.0001

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BCODE58	1	20.44792104	20.44792104	50.04	0.0001
BCODE59	1	6.65339570	6.65339570	16.28	0.0001
BCODE60	1	8.11979575	8.11979575	19.87	0.0001
BCODE61	1	37.66234549	37.66234549	92.16	0.0001
BCODE62	1	152.46017229	152.46017229	373.08	0.0001
BCODE63	1	201.92490924	201.92490924	494.13	0.0001
BCODE64	1	2.37954370	2.37954370	5.82	0.0158
BCODE65	1	15.95187237	15.95187237	39.04	0.0001
BCODE66	1	113.44983313	113.44983313	277.62	0.0001
BCODE67	1	129.73413759	129.73413759	317.47	0.0001
BCODE68	1	0.01116645	0.01116645	0.03	0.8687
BCODE69	1	146.49243687	146.49243687	358.48	0.0001
BCODE70	1	32.53541935	32.53541935	79.62	0.0001
BCODE71	1	59.99193830	59.99193830	146.81	0.0001
BCODE72	1	1.14985129	1.14985129	2.81	0.0935
BCODE73	1	26.96038556	26.96038556	65.97	0.0001
BCODE74	1	6.22251721	6.22251721	15.23	0.0001
BCODE75	1	9.24129452	9.24129452	22.61	0.0001
BCODE76	1	206.42821391	206.42821391	505.15	0.0001
BCODE77	1	40.06720368	40.06720368	98.05	0.0001
BCODE78	1	13.09450803	13.09450803	32.04	0.0001
BCODE79	1	52.03456877	52.03456877	127.33	0.0001
BCODE80	1	33.99662989	33.99662989	83.19	0.0001
BCODE81	1	20.96914900	20.96914900	51.31	0.0001
BCODE82	1	13.14181043	13.14181043	32.16	0.0001
BCODE83	1	70.09063241	70.09063241	171.52	0.0001
BCODE84	1	58.73200993	58.73200993	143.72	0.0001
BCODE85	1	19.31141319	19.31141319	47.26	0.0001
BCODE86	1	514.67657052	514.67657052	1259.46	0.0001
BCODE87	1	12.74914366	12.74914366	31.20	0.0001
BCODE88	1	252.13013254	252.13013254	616.99	0.0001
BCODE89	1	38.28312489	38.28312489	93.68	0.0001
BCODE90	1	34.30219434	34.30219434	83.94	0.0001
BCODE91	1	11.81952731	11.81952731	28.92	0.0001
BCODE92	1	0.03652594	0.03652594	0.09	0.7650
BCODE93	1	5.92422360	5.92422360	14.50	0.0001
BCODE94	1	10.39695480	10.39695480	25.44	0.0001
BCODE95	1	35.92919344	35.92919344	87.92	0.0001
BCODE96	1	84.32616569	84.32616569	206.35	0.0001
BCODE97	1	151.94226064	151.94226064	371.82	0.0001
BCODE98	1	0.00253324	0.00253324	0.01	0.9372
BCODE99	1	19.22530436	19.22530436	47.05	0.0001
BCODE100	1	4.63433365	4.63433365	11.34	0.0008
BCODE101	1	202.76166611	202.76166611	496.18	0.0001
BCODE102	1	33.74005969	33.74005969	82.56	0.0001
BCODE103	1	0.72468724	0.72468724	1.77	0.1830
BCODE104	1	59.74361540	59.74361540	146.20	0.0001
BCODE105	1	2.87178445	2.87178445	7.03	0.0080
BCODE106	1	25.43252482	25.43252482	62.24	0.0001
BCODE107	1	18.29241131	18.29241131	44.76	0.0001
BCODE108	1	17.69974318	17.69974318	43.31	0.0001
BCODE109	1	5.61378556	5.61378556	13.74	0.0002
BCODE110	1	42.52128261	42.52128261	104.05	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BYCATCH	1	0.02407662	0.02407662	0.06	0.8082
BYCAT2	1	123.29199976	123.29199976	301.71	0.0001
YEAR79*D1	1	0.67384864	0.67384864	1.65	0.1991
YEAR79*D2	1	1.64213447	1.64213447	4.02	0.0450
YEAR79*D3	1	0.70559579	0.70559579	1.73	0.1888
YEAR79*D4	1	4.88685513	4.88685513	11.96	0.0005
YEAR80*D1	0	0.00000000	.	.	.
YEAR80*D2	1	0.01688538	0.01688538	0.04	0.8389
YEAR80*D3	1	2.22480808	2.22480808	5.44	0.0196
YEAR80*D4	1	0.24607745	0.24607745	0.60	0.4378
YEAR81*D1	1	0.80072563	0.80072563	1.96	0.1616
YEAR81*D2	1	3.13472711	3.13472711	7.67	0.0056
YEAR81*D3	1	15.94734579	15.94734579	39.02	0.0001
YEAR81*D4	1	4.17356922	4.17356922	10.21	0.0014
YEAR82*D1	1	2.81019878	2.81019878	6.88	0.0087
YEAR82*D2	1	0.18423610	0.18423610	0.45	0.5019
YEAR82*D3	1	11.44682528	11.44682528	28.01	0.0001
YEAR82*D4	1	0.00106559	0.00106559	0.00	0.9593
YEAR83*D1	0	0.00000000	.	.	.
YEAR83*D2	1	0.00988585	0.00988585	0.02	0.8764
YEAR83*D3	1	1.14973990	1.14973990	2.81	0.0935
YEAR83*D4	1	1.08577976	1.08577976	2.66	0.1031
YEAR84*D1	1	1.69568833	1.69568833	4.15	0.0416
YEAR84*D2	1	0.83075787	0.83075787	2.03	0.1539
YEAR84*D3	1	0.34994711	0.34994711	0.86	0.3548
YEAR84*D4	1	3.55528729	3.55528729	8.70	0.0032
YEAR85*D1	1	0.27750986	0.27750986	0.68	0.4099
YEAR85*D2	1	0.29524790	0.29524790	0.72	0.3953
YEAR85*D3	1	0.23007226	0.23007226	0.56	0.4531
YEAR85*D4	1	0.00370125	0.00370125	0.01	0.9242
YEAR86*D1	1	0.23419202	0.23419202	0.57	0.4490
YEAR86*D2	1	0.15729104	0.15729104	0.38	0.5350
YEAR86*D3	1	5.36400317	5.36400317	13.13	0.0003
YEAR86*D4	1	0.31040829	0.31040829	0.76	0.3835
YEAR87*D1	1	1.00062517	1.00062517	2.45	0.1176
YEAR87*D2	1	0.00058810	0.00058810	0.00	0.9697
YEAR87*D3	1	0.01902464	0.01902464	0.05	0.8292
YEAR87*D4	1	0.26683100	0.26683100	0.65	0.4191
YEAR88*D1	1	1.67296035	1.67296035	4.09	0.0430
YEAR88*D2	1	17.06928809	17.06928809	41.77	0.0001
YEAR88*D3	1	1.26845110	1.26845110	3.10	0.0781
YEAR88*D4	1	0.75076003	0.75076003	1.84	0.1753
YEAR89*D1	0	0.00000000	.	.	.
YEAR89*D2	1	17.85949888	17.85949888	43.70	0.0001
YEAR89*D3	1	13.31901426	13.31901426	32.59	0.0001
YEAR89*D4	1	1.93696515	1.93696515	4.74	0.0295
YEAR90*D1	1	0.22171148	0.22171148	0.54	0.4614
YEAR90*D2	1	51.70911445	51.70911445	126.54	0.0001
YEAR90*D3	1	65.31607439	65.31607439	159.83	0.0001
YEAR90*D4	1	10.43316618	10.43316618	25.53	0.0001
YEAR91*D1	1	0.01140654	0.01140654	0.03	0.8673
YEAR91*D2	1	8.09273033	8.09273033	19.80	0.0001
YEAR91*D3	1	77.62071327	77.62071327	189.94	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR91*D4	1	17.26402121	17.26402121	42.25	0.0001
YEAR92*D1	0	0.00000000	.	.	.
YEAR92*D2	1	8.65055287	8.65055287	21.17	0.0001
YEAR92*D3	1	15.94998914	15.94998914	39.03	0.0001
YEAR92*D4	1	6.07450698	6.07450698	14.86	0.0001
YEAR93*D1	1	0.34258325	0.34258325	0.84	0.3599
YEAR93*D2	1	6.79008286	6.79008286	16.62	0.0001
YEAR93*D3	1	65.82814225	65.82814225	161.09	0.0001
YEAR93*D4	1	11.48570613	11.48570613	28.11	0.0001
YEAR94*D1	0	0.00000000	.	.	.
YEAR94*D2	1	21.28045334	21.28045334	52.08	0.0001
YEAR94*D3	1	42.52103586	42.52103586	104.05	0.0001
YEAR94*D4	1	1.13416660	1.13416660	2.78	0.0957
YEAR79*LAT2	1	16.63909096	16.63909096	40.72	0.0001
YEAR79*LAT3	1	6.25638555	6.25638555	15.31	0.0001
YEAR79*LAT4	1	0.00213195	0.00213195	0.01	0.9424
YEAR80*LAT2	1	3.66825357	3.66825357	8.98	0.0027
YEAR80*LAT3	1	8.18309374	8.18309374	20.02	0.0001
YEAR80*LAT4	1	2.01908135	2.01908135	4.94	0.0262
YEAR81*LAT2	1	0.54184357	0.54184357	1.33	0.2495
YEAR81*LAT3	1	0.20069217	0.20069217	0.49	0.4834
YEAR81*LAT4	1	0.64824891	0.64824891	1.59	0.2079
YEAR82*LAT2	1	5.55843476	5.55843476	13.60	0.0002
YEAR82*LAT3	1	7.63351982	7.63351982	18.68	0.0001
YEAR82*LAT4	1	11.00769781	11.00769781	26.94	0.0001
YEAR83*LAT2	1	0.99857616	0.99857616	2.44	0.1180
YEAR83*LAT3	1	3.69318134	3.69318134	9.04	0.0026
YEAR83*LAT4	1	10.47803506	10.47803506	25.64	0.0001
YEAR84*LAT2	1	1.81962481	1.81962481	4.45	0.0348
YEAR84*LAT3	1	1.91848445	1.91848445	4.69	0.0303
YEAR84*LAT4	1	0.66560018	0.66560018	1.63	0.2019
YEAR85*LAT2	1	1.22862498	1.22862498	3.01	0.0829
YEAR85*LAT3	1	5.78930496	5.78930496	14.17	0.0002
YEAR85*LAT4	1	1.01975330	1.01975330	2.50	0.1142
YEAR86*LAT2	1	3.67776313	3.67776313	9.00	0.0027
YEAR86*LAT3	1	4.14144609	4.14144609	10.13	0.0015
YEAR86*LAT4	1	0.32882369	0.32882369	0.80	0.3697
YEAR87*LAT2	1	0.00353450	0.00353450	0.01	0.9259
YEAR87*LAT3	1	0.08829174	0.08829174	0.22	0.6421
YEAR87*LAT4	1	0.72891519	0.72891519	1.78	0.1817
YEAR88*LAT2	1	0.00634452	0.00634452	0.02	0.9008
YEAR88*LAT3	1	10.75393689	10.75393689	26.32	0.0001
YEAR88*LAT4	1	30.01580863	30.01580863	73.45	0.0001
YEAR89*LAT2	1	1.39674841	1.39674841	3.42	0.0645
YEAR89*LAT3	1	4.15236327	4.15236327	10.16	0.0014
YEAR89*LAT4	1	13.07038879	13.07038879	31.98	0.0001
YEAR90*LAT2	1	0.25561241	0.25561241	0.63	0.4290
YEAR90*LAT3	1	0.11872670	0.11872670	0.29	0.5899
YEAR90*LAT4	1	9.23559479	9.23559479	22.60	0.0001
YEAR91*LAT2	1	10.23004544	10.23004544	25.03	0.0001
YEAR91*LAT3	1	18.75642817	18.75642817	45.90	0.0001
YEAR91*LAT4	1	2.19192933	2.19192933	5.36	0.0206
YEAR92*LAT2	1	17.68013687	17.68013687	43.26	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR92*LAT3	1	17.87190248	17.87190248	43.73	0.0001
YEAR92*LAT4	1	0.61823739	0.61823739	1.51	0.2187
YEAR93*LAT2	1	13.20862297	13.20862297	32.32	0.0001
YEAR93*LAT3	1	10.48719632	10.48719632	25.66	0.0001
YEAR93*LAT4	1	6.76218810	6.76218810	16.55	0.0001
YEAR94*LAT2	1	0.03539468	0.03539468	0.09	0.7685
YEAR94*LAT3	1	2.23450473	2.23450473	5.47	0.0194
YEAR94*LAT4	1	3.10388203	3.10388203	7.60	0.0059
D1*LAT2	0	0.00000000	.	.	.
D1*LAT3	1	0.10588129	0.10588129	0.26	0.6107
D1*LAT4	1	1.26351477	1.26351477	3.09	0.0787
D2*LAT2	1	5.07688049	5.07688049	12.42	0.0004
D2*LAT3	1	4.40531542	4.40531542	10.78	0.0010
D2*LAT4	1	6.49804286	6.49804286	15.90	0.0001
D3*LAT2	1	38.82223208	38.82223208	95.00	0.0001
D3*LAT3	1	78.88772588	78.88772588	193.05	0.0001
D3*LAT4	1	42.51722931	42.51722931	104.04	0.0001
D4*LAT2	1	10.74578954	10.74578954	26.30	0.0001
D4*LAT3	1	51.83027379	51.83027379	126.83	0.0001
D4*LAT4	1	51.67160348	51.67160348	126.45	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	2.918183693	69.59	0.0001	0.04193499
YEAR79	0.228791815	4.75	0.0001	0.04811676
YEAR80	0.066390391	1.40	0.1602	0.04727295
YEAR81	-0.145365742	-3.08	0.0021	0.04726757
YEAR82	0.034876408	0.71	0.4769	0.04903464
YEAR83	0.160470561	3.19	0.0014	0.05025116
YEAR84	0.161663563	3.22	0.0013	0.05015538
YEAR85	0.289165809	5.79	0.0001	0.04991483
YEAR86	0.142393350	2.81	0.0049	0.05063943
YEAR87	-0.055558672	-1.21	0.2246	0.04575228
YEAR88	-0.176550249	-3.73	0.0002	0.04731857
YEAR89	-0.060800782	-1.32	0.1878	0.04616127
YEAR90	0.098256217	1.96	0.0503	0.05019747
YEAR91	0.501024020	9.87	0.0001	0.05078584
YEAR92	0.368453671	7.81	0.0001	0.04720158
YEAR93	0.371031298	8.42	0.0001	0.04408351
YEAR94	0.096412262	1.94	0.0527	0.04977405
D1	-0.392123613	-0.84	0.3996	0.46550233
D2	-0.363172787	-5.49	0.0001	0.06610972
D3	-0.443135448	-14.96	0.0001	0.02961637
D4	-0.207683792	-8.02	0.0001	0.02588714
LAT2	0.162643677	4.21	0.0001	0.03859036
LAT3	0.075914472	1.96	0.0501	0.03874570
LAT4	-0.061385556	-1.43	0.1531	0.04296968
AUTUMN	0.134655669	26.79	0.0001	0.00502711
WINTER	0.117905070	22.33	0.0001	0.00527907
SPRING	-0.098395153	-18.59	0.0001	0.00529311
BCODE2	0.000163643	0.01	0.9942	0.02252436

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
BCODE3	-0.018496878	-0.84	0.4023	0.02208717
BCODE4	-0.600996422	-21.96	0.0001	0.02736794
BCODE5	-0.520640645	-10.83	0.0001	0.04807643
BCODE6	-0.634834249	-17.48	0.0001	0.03632813
BCODE7	0.002333982	0.10	0.9218	0.02378016
BCODE8	-0.744621656	-29.40	0.0001	0.02532342
BCODE9	-0.710870156	-28.88	0.0001	0.02461288
BCODE10	0.007392923	0.34	0.7306	0.02147342
BCODE11	-0.084385502	-3.75	0.0002	0.02252762
BCODE12	-0.709460162	-29.52	0.0001	0.02403616
BCODE13	-0.734348044	-28.01	0.0001	0.02621353
BCODE14	-0.592619505	-14.18	0.0001	0.04178317
BCODE15	0.004089057	0.17	0.8630	0.02369102
BCODE16	-0.767151256	-23.95	0.0001	0.03202795
BCODE17	-0.684413120	-25.29	0.0001	0.02706793
BCODE18	-0.578051769	-23.42	0.0001	0.02467872
BCODE19	-0.548919275	-24.13	0.0001	0.02275010
BCODE20	-0.480592629	-21.36	0.0001	0.02249914
BCODE21	-0.549728271	-24.96	0.0001	0.02202432
BCODE22	0.125154890	6.03	0.0001	0.02073975
BCODE23	-0.757105112	-26.34	0.0001	0.02874894
BCODE24	-0.722995301	-27.88	0.0001	0.02593671
BCODE25	0.015546933	0.70	0.4842	0.02222592
BCODE26	-0.764762856	-34.87	0.0001	0.02192956
BCODE27	0.082357409	4.00	0.0001	0.02057494
BCODE28	-0.076593942	-3.37	0.0007	0.02271285
BCODE29	-0.006917488	-0.33	0.7386	0.02073122
BCODE30	0.049585721	2.07	0.0381	0.02391474
BCODE31	0.004084572	0.18	0.8605	0.02323422
BCODE32	-0.143790519	-3.35	0.0008	0.04297395
BCODE33	-0.115646102	-3.79	0.0002	0.03054843
BCODE34	-0.253848256	-9.35	0.0001	0.02714146
BCODE35	-0.196755071	-3.48	0.0005	0.05655672
BCODE36	-0.164983960	-5.89	0.0001	0.02801935
BCODE37	0.137655459	6.31	0.0001	0.02180760
BCODE38	-0.281898447	-13.73	0.0001	0.02052541
BCODE39	-0.348699214	-17.11	0.0001	0.02037543
BCODE40	-0.283063875	-11.53	0.0001	0.02455891
BCODE41	-0.071256327	-3.52	0.0004	0.02021530
BCODE42	0.022186950	1.17	0.2436	0.01902761
BCODE43	-0.610676507	-20.64	0.0001	0.02958270
BCODE44	-0.036565566	-0.92	0.3599	0.03993658
BCODE45	-0.384045698	-17.67	0.0001	0.02173901
BCODE46	-0.133146785	-4.87	0.0001	0.02735034
BCODE47	-0.264109239	-10.16	0.0001	0.02599392
BCODE48	-0.369229941	-13.16	0.0001	0.02804701
BCODE49	-0.355303651	-15.23	0.0001	0.02332493
BCODE50	-0.180610644	-9.37	0.0001	0.01926690
BCODE51	-0.509063500	-19.13	0.0001	0.02661619
BCODE52	-0.718531774	-14.84	0.0001	0.04840502
BCODE53	-0.353741814	-15.44	0.0001	0.02290551
BCODE54	-0.337351394	-15.90	0.0001	0.02121812

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
BCODE107	0.220107744	6.69	0.0001	0.03289840
BCODE108	0.262142458	6.58	0.0001	0.03983170
BCODE109	-0.167503078	-3.71	0.0002	0.04519286
BCODE110	0.740184282	10.20	0.0001	0.07256240
BYCATCH	0.000233608	0.24	0.8082	0.00096242
BYCAT2	-0.000517660	-17.37	0.0001	0.00002980
YEAR79*D1	0.572859079	1.28	0.1991	0.44610961
YEAR79*D2	-0.125335421	-2.00	0.0450	0.06252366
YEAR79*D3	0.040381220	1.31	0.1888	0.03073098
YEAR79*D4	-0.089492580	-3.46	0.0005	0.02587899
YEAR80*D1	0.000000000 B	.	.	.
YEAR80*D2	0.011174881	0.20	0.8389	0.05497465
YEAR80*D3	0.067210641	2.33	0.0196	0.02880492
YEAR80*D4	0.018611614	0.78	0.4378	0.02398408
YEAR81*D1	0.638967880	1.40	0.1616	0.45646987
YEAR81*D2	0.157014111	2.77	0.0056	0.05669096
YEAR81*D3	0.185548261	6.25	0.0001	0.02970213
YEAR81*D4	0.080903106	3.20	0.0014	0.02531549
YEAR82*D1	1.257597887	2.62	0.0087	0.47956584
YEAR82*D2	-0.043618412	-0.67	0.5019	0.06496171
YEAR82*D3	0.153907824	5.29	0.0001	0.02907991
YEAR82*D4	-0.001287150	-0.05	0.9593	0.02520626
YEAR83*D1	0.000000000 B	.	.	.
YEAR83*D2	0.011035154	0.16	0.8764	0.07094902
YEAR83*D3	0.050985827	1.68	0.0935	0.03039657
YEAR83*D4	-0.042150238	-1.63	0.1031	0.02585855
YEAR84*D1	0.918650771	2.04	0.0416	0.45097492
YEAR84*D2	-0.086347565	-1.43	0.1539	0.06056027
YEAR84*D3	0.027307288	0.93	0.3548	0.02950885
YEAR84*D4	-0.074880301	-2.95	0.0032	0.02538664
YEAR85*D1	0.614900057	0.82	0.4099	0.74617430
YEAR85*D2	-0.078165618	-0.85	0.3953	0.09195965
YEAR85*D3	0.024965946	0.75	0.4531	0.03327292
YEAR85*D4	-0.002546757	-0.10	0.9242	0.02676014
YEAR86*D1	0.325651817	0.76	0.4490	0.43017227
YEAR86*D2	0.047710915	0.62	0.5350	0.07690255
YEAR86*D3	0.111858490	3.62	0.0003	0.03087446
YEAR86*D4	0.022345966	0.87	0.3835	0.02563937
YEAR87*D1	0.834001754	1.56	0.1176	0.53297423
YEAR87*D2	0.003926170	0.04	0.9697	0.10349476
YEAR87*D3	-0.006145832	-0.22	0.8292	0.02848377
YEAR87*D4	-0.019559128	-0.81	0.4191	0.02420507
YEAR88*D1	1.029197286	2.02	0.0430	0.50866373
YEAR88*D2	-0.534627372	-6.46	0.0001	0.08272151
YEAR88*D3	-0.054380697	-1.76	0.0781	0.03086618
YEAR88*D4	-0.036748504	-1.36	0.1753	0.02711216
YEAR89*D1	0.000000000 B	.	.	.
YEAR89*D2	-0.486539588	-6.61	0.0001	0.07359673
YEAR89*D3	-0.173904246	-5.71	0.0001	0.03046135
YEAR89*D4	-0.057297969	-2.18	0.0295	0.02631802
YEAR90*D1	-0.392668361	-0.74	0.4614	0.53309766
YEAR90*D2	-0.951397389	-11.25	0.0001	0.08457721

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
YEAR90*D3	-0.417600186	-12.64	0.0001	0.03303130
YEAR90*D4	-0.136376789	-5.05	0.0001	0.02699028
YEAR91*D1	-0.128125200	-0.17	0.8673	0.76688916
YEAR91*D2	-0.564326996	-4.45	0.0001	0.12681139
YEAR91*D3	-0.462537532	-13.78	0.0001	0.03356086
YEAR91*D4	-0.164845059	-6.50	0.0001	0.02536179
YEAR92*D1	0.000000000 B	.	.	.
YEAR92*D2	-0.749701825	-4.60	0.0001	0.16294521
YEAR92*D3	-0.210774716	-6.25	0.0001	0.03373753
YEAR92*D4	-0.101055855	-3.86	0.0001	0.02621084
YEAR93*D1	-0.703572349	-0.92	0.3599	0.76842353
YEAR93*D2	-0.631453221	-4.08	0.0001	0.15490970
YEAR93*D3	-0.421106727	-12.69	0.0001	0.03317885
YEAR93*D4	-0.132033213	-5.30	0.0001	0.02490458
YEAR94*D1	0.000000000 B	.	.	.
YEAR94*D2	-0.990119537	-7.22	0.0001	0.13720570
YEAR94*D3	-0.345882097	-10.20	0.0001	0.03390792
YEAR94*D4	0.042266342	1.67	0.0957	0.02537063
YEAR79*LAT2	-0.305258142	-6.38	0.0001	0.04783849
YEAR79*LAT3	-0.185447959	-3.91	0.0001	0.04739530
YEAR79*LAT4	0.003741560	0.07	0.9424	0.05180117
YEAR80*LAT2	-0.139701664	-3.00	0.0027	0.04662801
YEAR80*LAT3	-0.209824725	-4.47	0.0001	0.04688920
YEAR80*LAT4	-0.112354871	-2.22	0.0262	0.05054637
YEAR81*LAT2	0.052785753	1.15	0.2495	0.04584107
YEAR81*LAT3	-0.032101981	-0.70	0.4834	0.04580803
YEAR81*LAT4	0.062134227	1.26	0.2079	0.04933271
YEAR82*LAT2	-0.178061170	-3.69	0.0002	0.04828007
YEAR82*LAT3	-0.207454072	-4.32	0.0001	0.04799926
YEAR82*LAT4	-0.266643373	-5.19	0.0001	0.05137567
YEAR83*LAT2	-0.077361292	-1.56	0.1180	0.04948893
YEAR83*LAT3	-0.149014798	-3.01	0.0026	0.04956830
YEAR83*LAT4	-0.267334683	-5.06	0.0001	0.05279470
YEAR84*LAT2	-0.105153787	-2.11	0.0348	0.04983207
YEAR84*LAT3	-0.107394710	-2.17	0.0303	0.04956541
YEAR84*LAT4	0.066883981	1.28	0.2019	0.05240713
YEAR85*LAT2	-0.086254285	-1.73	0.0829	0.04974460
YEAR85*LAT3	-0.183674809	-3.76	0.0002	0.04879905
YEAR85*LAT4	-0.082042648	-1.58	0.1142	0.05193583
YEAR86*LAT2	-0.152521055	-3.00	0.0027	0.05084086
YEAR86*LAT3	-0.158262611	-3.18	0.0015	0.04971384
YEAR86*LAT4	-0.047203054	-0.90	0.3697	0.05262153
YEAR87*LAT2	0.004239916	0.09	0.9259	0.04558983
YEAR87*LAT3	-0.020959918	-0.46	0.6421	0.04509252
YEAR87*LAT4	-0.065771136	-1.34	0.1817	0.04924610
YEAR88*LAT2	-0.005876678	-0.12	0.9008	0.04716365
YEAR88*LAT3	0.230892697	5.13	0.0001	0.04500921
YEAR88*LAT4	0.415678966	8.57	0.0001	0.04850181
YEAR89*LAT2	0.085677206	1.85	0.0645	0.04634268
YEAR89*LAT3	0.142202326	3.19	0.0014	0.04461018
YEAR89*LAT4	0.274686328	5.66	0.0001	0.04856996
YEAR90*LAT2	0.040772131	0.79	0.4290	0.05155222

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
YEAR90*LAT3	0.026176704	0.54	0.5899	0.04856414
YEAR90*LAT4	0.244347121	4.75	0.0001	0.05139842
YEAR91*LAT2	-0.258669403	-5.00	0.0001	0.05169889
YEAR91*LAT3	-0.344285466	-6.77	0.0001	0.05081812
YEAR91*LAT4	-0.125717391	-2.32	0.0206	0.05428215
YEAR92*LAT2	-0.318274795	-6.58	0.0001	0.04838763
YEAR92*LAT3	-0.310948055	-6.61	0.0001	0.04701944
YEAR92*LAT4	-0.061433998	-1.23	0.2187	0.04994662
YEAR93*LAT2	-0.256893715	-5.69	0.0001	0.04518556
YEAR93*LAT3	-0.223892903	-5.07	0.0001	0.04419627
YEAR93*LAT4	-0.199276236	-4.07	0.0001	0.04898768
YEAR94*LAT2	0.015260897	0.29	0.7685	0.05185445
YEAR94*LAT3	0.116090271	2.34	0.0194	0.04964553
YEAR94*LAT4	0.148361843	2.76	0.0059	0.05383250
D1*LAT2	0.000000000 B	.	.	.
D1*LAT3	0.191756731	0.51	0.6107	0.37671765
D1*LAT4	-0.499890134	-1.76	0.0787	0.28428855
D2*LAT2	0.191432135	3.52	0.0004	0.05431144
D2*LAT3	0.170481405	3.28	0.0010	0.05192344
D2*LAT4	0.204580085	3.99	0.0001	0.05130350
D3*LAT2	0.216776381	9.75	0.0001	0.02224061
D3*LAT3	0.292534513	13.89	0.0001	0.02105462
D3*LAT4	0.235469386	10.20	0.0001	0.02308484
D4*LAT2	0.104806136	5.13	0.0001	0.02043819
D4*LAT3	0.226255677	11.26	0.0001	0.02009013
D4*LAT4	0.254302301	11.24	0.0001	0.02261514

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.