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EXECUTIVE SUMMARY

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This research addresses Objective 1 of the Ministry of Fisheries project EMA200501 "To develop a fisheries dependent relative index, or set of indices, of abundance for blue mackerel (*Scomber australasicus*) up to the end of the 2003/2004 fishing year, and if possible up to the end of the 2004/2005 fishing year, for use in stock assessment

EMA 7 consists of a purse-seine target fishery and a midwater trawl bycatch fishery. The annual estimated catch is described by form type associated with the defined fishery. Each form type is further described by fishing year for fishing method, target species, statistical area, and month.

The CPUE standardisations were based on TCEPR tow by tow data from the midwater trawl jack mackerel target fishery for which blue mackerel form a significant and important bycatch. Tows that targeted jack mackerel but did not report any blue mackerel catch were considered to be zero tows.

Estimates of relative year effects were obtained using a forward stepwise multiple regression method, where the data were fitted using a binomial-lognormal model structure. The data used for the CPUE analyses consisted of catch and effort by core vessels that targeted jack mackerel. Core vessels were those vessels that had more than five non-zero tows of blue mackerel for at least 3 years.

Separate standardisations were carried out on two subgroups of core vessels corresponding to an early period from 1989–90 to 1997–98 and a late period from 1989–90 to 1997–98 of the data series. CPUE indices were developed for the early time series using catch and effort by 12 core vessels and the late time series using catch and effort by 7 core vessels.

For the early time series, the residual deviances explained were 19% for the binomial model and 33% for the lognormal model. For the late time series, the residual deviances explained were 18% for the binomial model and 30% for the lognormal model. For both data series, the main terms selected by the models are *statistical area, vessel,* and *month.*

The combined index produced for the early time series dropped to a minimum in 1992–93, increased in 1994–95, and then fluctuated to 1997–98. The combined index produced for the late time series fluctuated to 1999–2000, then declined through the years to a level in 2004–05 about 15% of the 1996–97 level.

For the early time series, the analysis showed uncertainty over trends in reporting. For the late time series, significant *year*statistical area* interactions were estimated, and large interannual variation in catches and CPUE were observed in some statistical areas. It is therefore premature to make conclusions about whether the indices represent trends in abundance.

1. INTRODUCTION

Blue mackerel was introduced into the Quota Management System (QMS) in 2002 and the fishery is currently managed as five separate fishstocks: EMA 1, 2, 3, 7, and 10 (Figure 1). Blue mackerel support a moderate volume fishery with catches exceeding 10 000 t in five of the past seven years (Ministry of Fisheries, Science Group 2006) (Table 1). In 1998–99 and 2000–01, commercial landings of over 13 000 t were taken, with the highest catches recorded in EMA 1. EMA 7 is located off the west coast of the North and South Islands, and supports the second largest commercial fishery of blue mackerel in New Zealand. The landings in EMA 7 fluctuated between 2700 t and 5100 t in the past five years, exceeding the TACC of 3350 t in 2004–05 and 2005–06. The blue mackerel catch in EMA 7 was mainly taken from the target purse-seine fishery, and as non-target catch in the jack mackerel midwater trawl fishery.

Little is known about the status of blue mackerel stocks, and estimates of current and reference biomass, or yield, are unavailable for this species. It is unknown whether recent catch levels are sustainable or at levels that will allow the stock to move towards a size that will support the MSY (Sullivan et al. 2005). In the absence of a formal stock assessment, monitoring of the stock is based on catch sampling, evaluation of fishery-dependent abundance indices, and comparing landings with the TAC (EMA200301 & EMA200401).

Taylor (2002) argued that CPUE of blue mackerel catch in EMA 7 in the jack mackerel midwater trawl fishery may not provide a reliable set of indices for inclusion in models assessing the fishstock abundance for several reasons.

- There is little use of CPUE as an index of abundance in fisheries for species of *Scomber* elsewhere.
- A situation similar to the Canadian scombrid mackerel fishery is probable, where CPUE from the trawl fishery would provide stock indices that are more a reflection of fishing power and fish distribution than of stock abundance.
- The distribution of blue mackerel encountered in this fishery is almost certainly highly variable.
- About 95% of blue mackerel catch is taken as bycatch.

It is often considered to be an effective option to estimate standardised CPUE indices from data for targeted catch. However, current work on the development of a CPUE index for jack mackerel abundance in the JMA 7 midwater trawl fishery used tows that targeted species other than jack mackerel based on the rationale that 'these tows would be more likely to mimic random sampling of jack mackerel densities' (Sampson 2001). This was largely unsuccessful because data were not representative throughout the geographical range. A similar approach could be employed for blue mackerel.

The analyses developed CPUE indices for blue mackerel in EMA 7, using commercial catch and effort data from 1989–90 to 2004–05. This, in combination with recent research on blue mackerel (EMA200202, EMA200301, EMA200401), will provide a basis for a future stock assessment. This research addresses Objective 1 of the Ministry of Fisheries project EMA200501 "To develop a fisheries dependent relative index, or set of indices, of abundance for blue mackerel up to the end of the 2003–2004 fishing year, and if possible up to the end of the 2004–2005 fishing year, for use in stock assessment"

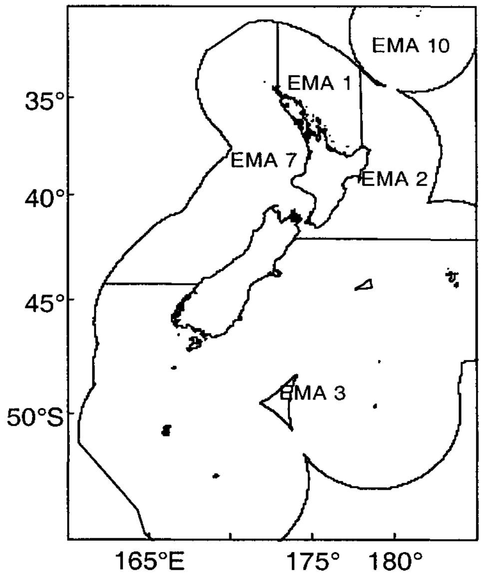

Figure 1: Quota Management Areas (QMAs) EMA 1, 2, 3, 7, and 10.

Table 1: Reported landings (t) of blue mackerel by QMA and where area was unspecified (Unsp.), from 1983–84 to 2004–05. After Ministry of Fisheries, Science Group 2006.

QMA	1	2	3	7	10#	Unsp	Total
1983–84*	480	259	44	245	0	1	1 028
1984–85*	565	222	18	865	0	73	1 743
1985–86*	618	30	190	408	0	51	1 296
1986–87†	1 431	7	424	489	0	49	2 399
1987–88†	2 641	168	864	1 896	0	58	5 625
1988–89†	1 580	<1	1 141	1 021	0	469	4 211
1989–90†	2 158	76	518	1 492	0	<1	4 245
1990–91†	5 783	94	478	3 004	0	0	9 358
1991–92†	10 926	530	65	3 607	0	0	15 128
1992–93†	10 684	309	133	1 880	0	0	13 006
1993–94†	4 178	218	223	1 402	5	0	6 025
1994–95†	6 734	94	154	1 804	10	149	8 944
1995–96†	4 170	119	173	1 218	0	1	5 680
1996–97†	6 754	78	340	2 537	0	<1	9 708
1997–98†	4 595	122	78	2 310	0	<1	7 104
1998–99†	4 505	186	62	8 756	0	4	13 519
1999–00†	3 602	73	3	3 169	0	0	6 847
2000–01†	9 738	113	6	3 278	0	<1	13 134
2001–02‡	6 368	177	49	5 101	0	0	11 694
2002-03‡	7 609	115	88	3 563	0	0	11 375
2003–04‡	6 523	149	1	2 701	0	0	9 373
2004-05‡	7 920	8	<1	4 817	0	0	12 746

* FSU data.
† CELR data.
# Landings reported from QMA 10 are probably attributable to Statistical Area 010 in the Bay of Plenty (i.e., QMA 1).
‡ QMS data.

2. METHODS

Standardised CPUE analysis, based on procedures explained by Vignaux (1994) and modified by Francis (1999), uses Generalised Linear Models (GLM) to express the catch per unit effort as being dependent upon a set of explanatory variables in a multiplicative manner. The relative year effects calculated from the regression coefficients represent the change in CPUE through time, having adjusted for effects of other conditions or fishing patterns, such as gear type, or time and place of fishing.

2.1 Description of the data

Catch and effort data were extracted from the Ministry of Fisheries catch-effort database "warehou", and included fishing events (tows or sets) where blue mackerel were either caught or targeted in statistical areas within EMA 7 (Figure 2) from 1989–90 to 2004–05. Tows by midwater trawls that targeted jack mackerel in JMA 7 were also included as blue mackerel form a significant and important bycatch in the more predominant jack mackerel fishery there.

The extracted data were initially recorded on Catch, Effort, and Landing Return forms (CELR) and Trawl, Catch, Effort and Processing Returns forms (TCEPR). TCEPR forms record tow-by-tow data and summarise the estimated catch for the top five species (by weight) for individual tows. CELR forms summarise daily catches, which are further stratified by date, statistical area, method of capture, and target species. Longline and setnet landings are always recorded on CELR forms, while trawl vessels less than 28 m in length can use either CELR or TCEPR forms. Trawl vessels over 28 m use TCEPR forms.

Most of the variables extracted from the catch-effort database are self-explanatory and are summarised in Table 2. The position information for individual fishing event is given by *latitude* and *longitude* for TCEPRs and by statistical area for CELRs.

Table 2: Variables in the CPUE data set.

Variable	Type	Description
Fishing Year	Categorical	Fishing year (starting from 1 Oct)
Month	Categorical	Calendar month of year
Vessel	Categorical	Unique vessel code
Gross tonnage	Continuous	Gross tonnage in metric tonnes of the vessel at the time of the tow
Engine kilowatts	Continuous	Engine power in kilowatts of the vessel at the time of the tow
Wingspread	Continuous	Wingspread in metres of the vessel at the time of the tow
Headline height	Continuous	Headline height in metres of the vessel at the time of the tow
Method	Categorical	Fishing gear (BT, MW, PS)
Stat area	Categorical	Statistical area fished
Target species	Categorical	Target species
Start longitude	Continuous	Longitude position at the start of the tow
Start latitude	Continuous	Latitude position at the start of the tow
Duration	Continuous	Total duration of trawling (h)
depth	Continuous	Ground rope depth of the tow
EMA catch	Continuous	Estimated catch of blue mackerel

Each fishing event also included estimated catch of other species (up to the top five). Jack mackerel, kahawai, barracouta, frostfish, and redbait are common species captured with blue mackerel. The estimated catch of those species was retained (0 if it wasn't recorded for that fishing event) and all the other species were ignored.

Catch-effort data can contain invalid codes and missing or implausible values. A simple consistency check was applied to the data as described below, and the groomed dataset is summarised in Table 3.

- 10 records containing missing values in vessel, method, or targeted species were deleted.
- Values of fishing duration of 0 or greater than 12 h for TCEPR, or of 0 or greater than 24 h for CELR, were replaced by the median value from the same vessel/day; 28 records were fixed.
- Values of ground rope depth of 0 or greater than 2000 m for TCEPR were replaced by the median value from the same vessel/day; 86 records were fixed.

Table 3: Number of records by fishing method and form type in the groomed CPUE data set. BT, bottom trawl; MW, midwater trawl; PS, purse-seine; SN, set net. Other includes bottom pair trawl, bottom longlining, beach seine, and Danish seine.

	BT	MW	PS	SN	Other	Total
CELR	60	0	378	1 035	54	1 527
TCEPR	2 132	19 727	0	0	12	21 871

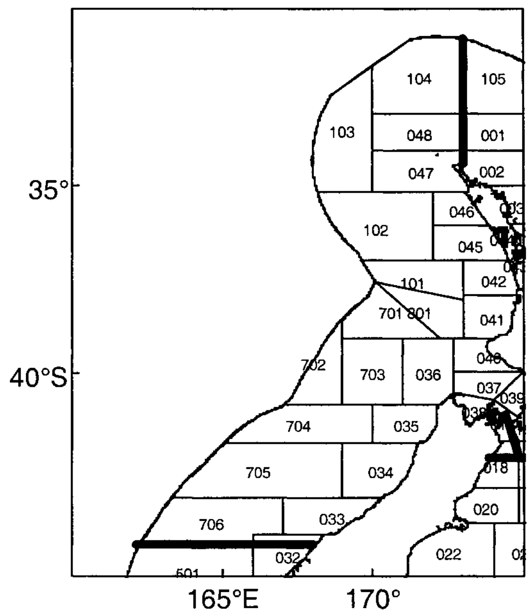

Figure 2: Statistical areas around northern New Zealand. The boundaries of the Quota Management Area (bold lines) do not completely coincide with those of the statistical areas.

2.2 Description of the fisheries

The catch and effort data were summarised to provide a description of the dynamics of the fisheries. The distribution of blue mackerel catches was examined for the CELR and TCEPR fleet separately because the composition of the CELR fishery is very different to that of the TCEPR (Table 3). The annual estimated catch is described by form type, and each form type is further described by fishing year for fishing method and target species. The spatial and temporal distribution of the purse-seine target fishery and the midwater trawl bycatch fishery is described by statistical area and month.

2. 3 CPUE standardisations

Based on the results of Taylor (2002), the target purse-seine fishery was unlikely to provide a reliable set of abundance indices as the distribution of the catch and effort (mainly recorded on CELRs) was patchy in time and space. The effective effort cannot be easily measured when the species school at the surface, and are bulk-caught in purse-seine nets with assistance of spotter planes.

The CPUE standardisations were based on TCEPR midwater trawl jack mackerel targeted tows in which blue mackerel were consistently taken as bycatch. Tows that targeted jack mackerel but did not report any blue mackerel catch were considered to be zero tows. As the proportion of zeros was usually high and varied from year to year, a binomial-lognormal model (Fletcher et al. 2005) was used to fit the data. The binomial-lognormal method assumes that the probability of obtaining any positive catches and the distribution of the positive catches are influenced by covariates (vessel, year, area, etc.) in different ways, and thus models the two aspects of the data separately. The method involves fitting a logistic regression to the proportion of non-zeros and a linear regression to the log-transformed positive catches. The year effects extracted from the two stages of model were then combined (Vignaux 1994) to produce the indices which are assumed to represent the yearly fluctuations in relative abundance.

Vessel effects were incorporated into the CPUE standardisation to allow for possible differences in fishing power between vessels. Vessels that were not involved in the fishery for consecutive years, or that had participated only for a couple of years, provide little information for the standardisations (Knuckey et al. 1998) and can result in model over-fitting (Francis 2001). Thus, CPUE analyses were undertaken for "core" vessels. The core vessels are those vessels that recorded more than five non-zero tows of blue mackerel in the midwater trawl jack mackerel target fishery each year for at least three consecutive years.

Candidate predictor variables offered to the model included fishing year, vessel, statistical area, month, and ground rope depth. The dependent variable for the logistic regression was a derived indicator variable (1 if any blue mackerel was caught or 0 otherwise). The dependent variable for the linear regression was the log-transformed catches per trawling hour. The candidate variables were selected iteratively in a stepwise fashion. The variable that resulted in the greatest improvement in Residual Square (R^2, also referred to as the percentage of deviance explained, which is equal to 1 minus the ratio of the deviance of the model to the deviance of the null model) was included in each step. A stopping rule of a 1% change in R^2 was used to produce a relatively parsimonious model with moderate explanatory power.

Model fits to the lognormal component of the combined model were investigated using standard residual diagnostics. For the binomial component, model fits were investigated visually using the plot of predicted probabilities vs. observed probabilities. The data were sorted and then divided into 100 bins. Observed probabilities were the proportion of non-zeros within each bin and predicted probabilities were the mean predicted probabilities within each bin.

3. RESULTS

3. 1 Descriptions of the fisheries

The distributions of annual estimated catch by form type, method, target species, statistical area, and month are summarised in Tables 4–14. The graphic representations of the spatial and temporal distributions of the catches are presented in Figures A1–A8 in Appendix A.

3.1.1 Annual catches

Annual catches of blue mackerel in EMA 7 fluctuated during the last 15 years, varying between 1500 t and 3500 t (Table 4). The catches peaked in 1998–99 with a record of 7756 t, about nine times that in 1995–96. The fishery has been exploited more in recent years compared to the early 1990s, with the catches rising above 2500 t and exceeding 4000 t in 2001–02 and again in 2004–05. Blue mackerel were captured by the TCEPR fleet mainly as bycatch, and by the CELR fleet mainly as target catch. Target catch taken by the CELR fleet contributed almost 50% of the peak in 1998–99. In general, catches reported on CELR forms are only a small proportion of the EMA 7 catches in most years (less than 20%). However, high catches by the purse-seine fleet (Taylor 2002) resulted in over 80% of the total catches of blue mackerel being reported on CELR forms in 1989–90 and 1992–93. The bycatch fishery reported on TCEPR forms appears to have exhibited a cyclic pattern after 1996–97, yielding over 2000 t annually and peaking at about 4000 t in 1998–99, 2001–02, and 2004–05.

Table 4: Annual estimated catch (t) and distribution (%) by form type in EMA 7. Year 1999 denotes fishing year 1998–99, etc.

Year	Catches(t)			Distribution (%)	
	CELR	TCEPR	Total	CELR	TCEPR
1990	1 159	198	1 356	85	15
1991	193	1 662	1 856	10	90
1992	64	2 945	3 010	2	98
1993	2 823	718	3 541	80	20
1994	249	850	1 099	23	77
1995	565	1 171	1 736	33	67
1996	209	672	882	24	76
1997	3	2 002	2 005	0	100
1998	83	2 033	2 115	4	96
1999	3 563	4 193	7 756	46	54
2000	535	2 435	2 970	18	82
2001	180	2457	2 637	7	93
2002	259	4087	4 345	6	94
2003	555	2172	2 727	20	80
2004	66	2404	2 469	3	97
2005	600	3936	4 535	13	87
Total	11 105	33 935	45 040	25	75

3.1.2 CELR fleet

Blue mackerel recorded on CELR forms were taken almost exclusively in the target purse-seine fishery (Tables 5, 6, Figures A1, A2). There was a negligible amount (less than 2%) taken by set net. Blue mackerel were also caught when jack mackerel and kahawai were targeted, but catches were generally insignificant and associated with large variations. Further examination revealed that jack mackerel and kahawai were also the top two species taken when blue mackerel were either caught or targeted in the fishery. Their annual catches exhibit similar trends to those of blue mackerel (Table 7).

Purse-seine target catches were aggregated by month and statistical area for each fishing year. As the exceptionally high catches in 1992–93 and 1998–99 dominated, the seasonality (Table 8, Figure A3) and spatial pattern (Table 9, Figure A4) of the fishery were unstable and difficult to interpret. For most years, the fishery performed relatively well between January and May and again in September and October. Fishing tended to concentrate near the top of North Island (Statistical Area 047), in Cook strait (Statistical Area 017), and in the area between the top of the South Island and the South Taranaki Bight (Statistical Areas 037–041)

Table 5: Distribution (%) of annual estimated catch (t) by fishing method as reported on CELR forms in EMA 7. BT, bottom trawl; PS, purse-seine; SN, set net. Other includes bottom longlining, beach seine, and Danish seine. Year 1999 denotes fishing year 1998–99, etc.

Year	BT	PS	SN	Other	Total (t)
1990		100			1 159
1991		98	2		193
1992		92	6	2	64
1993		99			2 823
1994		94	6		249
1995		97	3		565
1996		98	2		209
1997		4	94	2	3
1998		96	3		83
1999		100			3 563
2000	2	98			535
2001		99	1		180
2002		100			259
2003		100			555
2004		98	2		66
2005		100			600
Total		99	1		11 105

Table 6: Distribution (%) of annual estimated catch (t) by target species as reported on CELR forms in EMA 7. JMA, jack mackerel; EMA, blue mackerel; KAH kahawai; SKJ, skate; Other, all other species combined. Year 1999 denotes fishing year 1998–99, etc.

Year	JMA	EMA	KAH	SKJ	Other	Total (t)
1990	8	72	20			1 159
1991		94	5		2	193
1992	9	80	5		6	64
1993	4	92	1	3	1	2 823
1994	14	76	3		6	249
1995		88	10		3	565
1996	18	74	6		2	209
1997			3		96	3
1998	28	49	15		8	83
1999		100				3 563
2000		95	3		2	535
2001		99			1	180
2002		99				259
2003	6	90	4			555
2004	18	76	2	1	2	66
2005		94	5			600
Total	3	91	4	1	1	11 105

Table 7: The annual estimated catch (t) of blue mackerel (EMA), jack mackerel (JMA), and kahawai (KAH) for fishing events as reported on CELR in EMA 7 where blue mackerel were caught or targeted. Year 1999 denotes fishing year 1998–99, etc.

Year	EMA	JMA	KAH
1990	1 159	731	728
1991	193	134	179
1992	64	404	75
1993	2 823	1 540	378
1994	249	354	179
1995	565	35	143
1996	209	131	107
1997	3		
1998	83	161	13
1999	3 563	300	358
2000	535	156	221
2001	180	50	5
2002	259	4	18
2003	555	103	342
2004	66	374	59
2005	600	98	114

Table 8 : Distribution (%) of annual estimated catch (t) by month for the CELR purse-seine target fishery in EMA 7. 0 denotes < 0.5%. Year 1999 denotes fishing year 1998–99, etc.

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total (t)
1990				10	9	32	8					41	831
1991						100							181
1992												100	50
1993	12	21		13	22	33							2 594
1994	100												190
1995						81		19					492
1996	63	19			18								155
1997												100	0
1998		100										0	40
1999		2				42	22	33	1				3 548
2000		16					33	38	12				506
2001			0		0	69	31						177
2002	100												257
2003		0			0	88	12						496
2004						100							50
2005			0				64	36				0	567
Total	8	7	0	4	7	37	15	16	1			4	10 136

Table 9: Distribution (%) of annual estimated catch (t) by statistical area for the CELR purse-seine target fishery in EMA 7. 0 denotes < 0.5%. Year 1999 denotes fishing year 1998–99, etc.

Year	048	047	046	045	044	043	042	041	040	037	039	038	017	036	034	Total (t)
1990										51			49			831
1991											54	46				181
1992	40	60														50
1993		96							4							2 594
1994		100														190
1995		100														492
1996		63						19		18						155
1997										100						0
1998									100							40
1999							2		19	72	4		1	2		3 548
2000		16								84						506
2001									0	31			69			177
2002		100														257
2003		0					0		10	90						496
2004										100						50
2005					0					72	28					567
Total	0	36	0	0	0	0	1	0	9	43	4	1	6	1	0	10 136

3.1.3 TCEPR fleet

The TCEPR fleet reported blue mackerel catch by midwater trawl consistently over time, and it contributed over 96% of the total blue mackerel catches for the last 15 years (Table 10, Figure A5). There were also catches recorded from bottom trawling before 1998–99, accounting for between 10% and 20% of annual yields. Blue mackerel catch from bottom and midwater trawl methods was taken mostly as bycatch when jack mackerel were targeted (Table 11, Figure A6). The midwater trawl catch also consists of a target component, which was both insignificant (4% of total blue mackerel catches) and inconsistent with almost no recorded catches from 1992–93 to 1995–96 and again from 1999–2000 to 2001–02. Tows for which hoki (before 1997–98) or barracouta were targeted also caught a small amount of blue mackerel. For tows where blue mackerel were caught or targeted, a mixture of species were caught, including jack mackerel, barracouta, frostfish, and redbait (Table 12). The jack mackerel catches appeared to be strongly correlated with those of blue mackerel.

In contrast to the purse target fishery, the seasonality of the blue mackerel catch taken by the TCEPR midwater jack mackerel target fishery exhibited a clear pattern, where blue mackerel were mostly caught in the winter period with peaks in June and July (Table 13, Figure A7). In the two most recent years the catches increased in October and December.

The blue mackerel catch from the TCEPR midwater jack mackerel targeted tows shifted from the south to the north over time (Table 14, Figure A8). This appears to be the result of a northward movement of midwater trawl jack mackerel targeted effort in EMA 7 (McKenzie 2007, draft report under review for Ministry of Fisheries project JMA200402). Before 1999–2000, the catches were stable in Statistical Areas 034–037 off the west coast of South Island. Then there was a sharp increase of catches off the west coast of North Island in Statistical Areas 040–042 and 045, and far off shore in Statistical Area 801. The catches in Statistical Area 041 (the North Taranaki Bight) were consistently high in the last 4 years. In 2003–04 and 2004–05, over 95% of catches were taken from Statistical Areas 041–042 and 801.

Table 10: Distribution (%) of annual estimated catch (t) by method as reported on TCEPR forms in EMA 7. BT, bottom trawl; MW, midwater trawl. Year 1999 denotes fishing year 1998–99, etc.

Year	BT	MW	Total (t)
1990	68	32	198
1991	18	82	1 662
1992	14	86	2 945
1993	22	78	718
1994	11	89	850
1995	1	99	1 171
1996	10	90	672
1997	1	99	2 002
1998	11	89	2 033
1999		100	4 193
2000		100	2 435
2001		100	2 457
2002		100	4 087
2003		100	2 172
2004		100	2 404
2005		100	3 936
Total	4	96	33 935

Table 11: Distribution (%) of annual estimated catch (t) by target species as reported on TCEPR forms in EMA 7. JMA, jack mackerel; EMA, blue mackerel; HOK, hoki; BAR, barracouta; Other, all other species combined. Year 1999 denotes fishing year 1998–99, etc.

Year	BAR	EMA	HOK	JMA	Other	Total (t)
1990	1		3	96		198
1991		31	19	49		1 662
1992		1	1	98		2 945
1993	4		15	82		718
1994	1		28	72		850
1995	3		9	87	1	1 171
1996	7		14	78		672
1997	1	3	5	90		2 002
1998	4	2		94		2 033
1999		7		93		4 193
2000				99		2 435
2001	1			99		2 457
2002	1			98	1	4 087
2003		5		95		2 172
2004	4	5		91		2 404
2005	11	9		79		3 936
Total	2	4	3	90		33 935

Table 12: Catches (t) of blue mackerel and other species for fishing events as reported on TCEPR forms in EMA 7 where blue mackerel were either caught or targeted. JMA, jack mackerel; EMA, blue mackerel; BAR, barrakouta; FRO, frostfish; RBT, redbait. Year 1999 denotes fishing year 1998–99, etc.

Year	EMA	JMA	BAR	FRO	RBT
1990	198	3 882	273	120	0
1991	1 662	5 378	298	249	1
1992	2 945	8 461	715	331	45
1993	718	4 436	529	188	56
1994	850	3 951	305	167	54
1995	1 171	4 262	281	194	191
1996	672	2 038	647	246	114
1997	2 002	2 528	768	480	219
1998	2 033	4 979	1 383	302	110
1999	4 193	4 079	208	69	352
2000	2 435	3 173	215	87	314
2001	2 457	5 099	770	143	159
2002	4 087	6 279	868	78	548
2003	2 172	5 030	752	91	370
2004	2 404	9 053	882	237	697
2005	3 936	14 588	1 112	496	267

Table 13: Distribution (%) of annual estimated catch (t) by month for the TCEPR midwater trawl jack mackerel target fishery in EMA 7. 0 denotes < 0.5%. Year 1999 denotes fishing year 1998–99, etc.

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total (t)
1990	1		8	5	24	38	18		5		0		56
1991	0		0	1	3	3	0	1	66	22	1	2	526
1992	0	0	0	0	2	0	7	47	31	11		0	2 476
1993			0		5	3	2	14	27	47		2	437
1994	6		1	23	1			12	29	28		1	518
1995	2		0	16		5		16	44	17		0	1 006
1996						0		25	26	45	3	2	461
1997	0	0	1					2	42	45	5	6	1 793
1998	0		0			0	2	2	46	35	9	6	1 702
1999				0			3	6	55	34	0	1	3 877
2000	6		0	1			0		63	29		0	2 423
2001	0	0	2	4			0	3	62	28			2 425
2002	5	0	2	1				1	47	43	0	1	3 987
2003	6	1	2	0			6	2	72	8	3	0	2 066
2004	42	3	11	0				0	21	14	4	6	2 193
2005	37	2	17	4			0	0	8	32	0		3 117
Total	9	0	3	2	0	0	2	7	44	29	1	2	29 060

Table 14: Distribution (%) of annual estimated catch (t) by statistical area for the TCEPR midwater trawl jack mackerel target fishery in EMA 7. 0 denotes < 0.5%. Year 1999 denotes fishing year 1998–99, etc.

Year	047	046	045	042	041	801	040	037	039	038	017	036	703	035	034	Total (t)
1990					8	0	16	69	2			4		0		56
1991					5	1	4	6	3			5	7	55	14	526
1992			0		46	8	4	3	0			13		20	6	2 476
1993			0	2	2	4	5	6	0			42		37	2	437
1994				5	6	2	13	8				20		38	7	518
1995					12	4	12	6	1			16		41	8	1 006
1996		0				5	0	1				43		37	13	461
1997					1		0	0				8	0	63	28	1 793
1998					0		0	2	1			2	0	64	31	1 702
1999		0					2	1				12		74	12	3 877
2000							2	4				12	0	44	39	2 423
2001					20	4	6	2				17		32	21	2 425
2002					26	42	4	5	0			13		8	2	3 987
2003				1	41	16	8	7	0			6		16	3	2 066
2004			8	37	45	4	2	0				2		1		2 193
2005			13	15	44	20	2	0	0			4		3	0	3 117
Total	0	0	2	5	21	11	4	3	0	0	0	11	0	32	12	29 060

3.2 CPUE standardisations

Standardisation analyses were restricted to the TCEPR midwater trawls for which jack mackerel were targeted and to statistical areas where any catch of blue mackerel was recorded (Statistical Areas 034–037, 039–042, 045–046, and 801). Blue mackerel form a significant and important bycatch of the jack mackerel fishery and are almost exclusively taken by the jack mackerel target tows in the midwater fishery. The jack mackerel target tows were considered to be effective fishing effort with respect to blue mackerel. Tows that targeted jack mackerel but did not report any blue mackerel catch were considered to be zero tows

3.2.1 The selection of core vessels

Core vessels in the midwater trawl jack mackerel target fishery were defined as those vessels that recorded more than five non-zero tows of blue mackerel each year for at least three consecutive years. This effectively reduced the number of vessels from 58 to 19 but retained in total 87% of catches (Table 15). Those core vessels completely dominated the fishery after 1999–2000 but their numbers have declined from 12 in most years between 1993–94 and 1997–98 to 7 in the last three years. The distribution of effort for each of the core vessels is presented in Figure 3. There was clearly a temporal change in the fleet composition. Vessels 1–12 (vessel codes were assigned for identifying those vessels in the report and do not correspond to any real vessel code; see Figure 3) operated in the 1990s and nearly all of them appeared to have dropped out of the fishery by 1997–98. Vessels 13–19 dominated from the late 1990s, had far more tows, and had a longer presence in the fishery (vessels 14 and 15 had been fishing consistently since 1991–92). Vessel characteristics are presented in Figure 4. Vessels 13–19 were similar in length, had greater gross tonnage and engine power, and, on average, trawled faster than the rest of the fleet. Annual catches, the number of tows that targeted jack mackerel but caught blue mackerel (non-zero tows), the number of tows that targeted jack mackerel, and the encounter rate (the proportion of non-zero tows) by core vessels are summarised in Table 16. The encounter rate varied between 20% and 66%, indicating that the probabilities of catching any blue mackerel in the midwater trawl jack mackerel target fishery were associated with large variations.

Table 15: The annual number of core vessels, non-core vessels, and distribution (%) of estimated catch. Year 1999 denotes fishing year 1998–99, etc.

Year	Number of vessels		Catch (%)	
	Non-core	Core	Non-core	Core
1990	1	4	8	92
1991	6	6	51	49
1992	8	8	61	39
1993	2	6	25	75
1994	2	12	0	100
1995	10	12	19	81
1996	3	8	22	78
1997	9	11	28	72
1998	10	12	5	95
1999	6	9	21	79
2000	1	7	1	99
2001	1	7	0	100
2002	3	7	0	100
2003	1	7	0	100
2004	0	7	0	100
2005	1	7	0	100
Total	59	19	13	87

Table 16: The annual estimated catch (t), number of tows that targeted jack mackerel, number of tows that targeted jack mackerel but caught blue mackerel (non-zero tows), and proportion of non-zero tows by core vessels. Year 1999 denotes fishing year 1998–99, etc.

Year	Catch (t)	Tows (JMA)	Tows (EMA)	% Non-zero
1990	51	68	125	0.54
1991	257	177	269	0.66
1992	954	322	657	0.49
1993	327	135	529	0.26
1994	517	233	881	0.26
1995	810	415	1 055	0.39
1996	358	179	387	0.46
1997	1 281	299	788	0.38
1998	1 613	339	762	0.44
1999	3 046	536	1 087	0.49
2000	2 406	485	915	0.53
2001	2 425	514	1 461	0.35
2002	3 985	684	1 953	0.35
2003	2 065	504	2 558	0.20
2004	2 193	750	2 285	0.33
2005	3 117	976	2 376	0.41

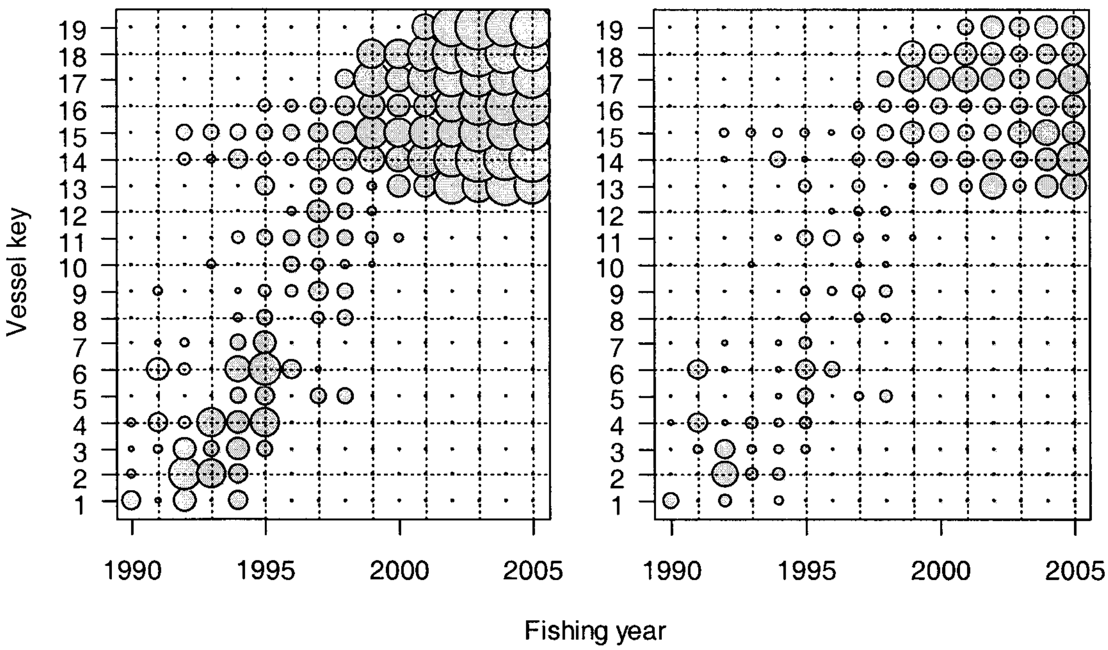

Figure 3: The distribution of effort (number of tows) by core vessels for tows that targeted jack mackerel (left) and tows that targeted jack mackerel but caught blue mackerel (right). The bubble area is proportional to number of tows and the largest circle represents 492 tows per year. Vessel keys are numerical codes assigned randomly to vessels. Year 1999 denotes 1998–99 fishing year, etc.

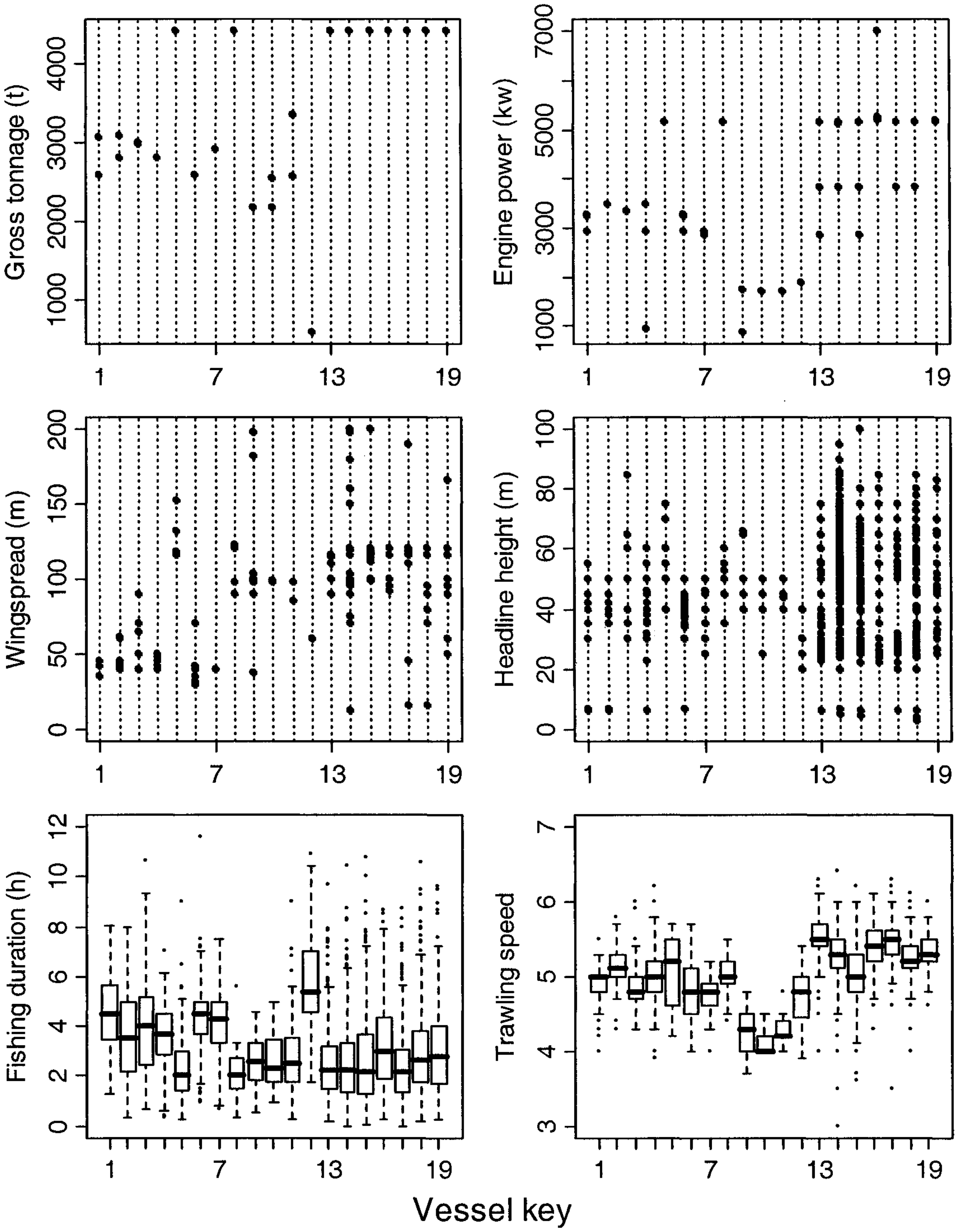

Figure 4: Characteristics of core vessels 1–19 for all years: dot charts of gross tonnage (t), engine power (kw), headline height (m), and wingspread (m), boxplots of fishing duration (h) and trawling speed (nautical mile). Vessel key is defined in Figure 3.

3.2.2 The split of the fishery

Based on the temporal change of fleet compositions, the Pelagic Working Group decided that the data series should be split into two parts and two CPUE indices calculated: an early time series from 1989–1990 to 1997–98 including vessels 1–12, and a late time series from 1996–1997 to 2004–05 including vessels 13–19 (see Figure 3). The timing for the split also took into account a number of changes in the JMA fishery from 1996 to1999 (McKenzie 2007, draft report under review for Ministry of Fisheries project JMA200402). The split in the data series coincided with the spatial shift in the fishery, where the early vessels mainly fished off the west coast of the south Island (Statistical Areas 034–037) and the late vessels gradually fished towards the north (Statistical Areas 040–042, 045, and 801). For the early time series (vessels 1–12) the encounter rate dropped from 60% to 20% in 1992–93, and the median catch rate (catches per tow, based on non-zero tows) remained relatively stable through the early 1990s (Figures 5, 6). For the late time series (vessels 13–19) the trends in encounter rates and median catch rates were fairly similar: both increased to 1998–99, decreased in the early 2000s, and then, for encounter rates only, increased again in 2003–04 and 2004–05.

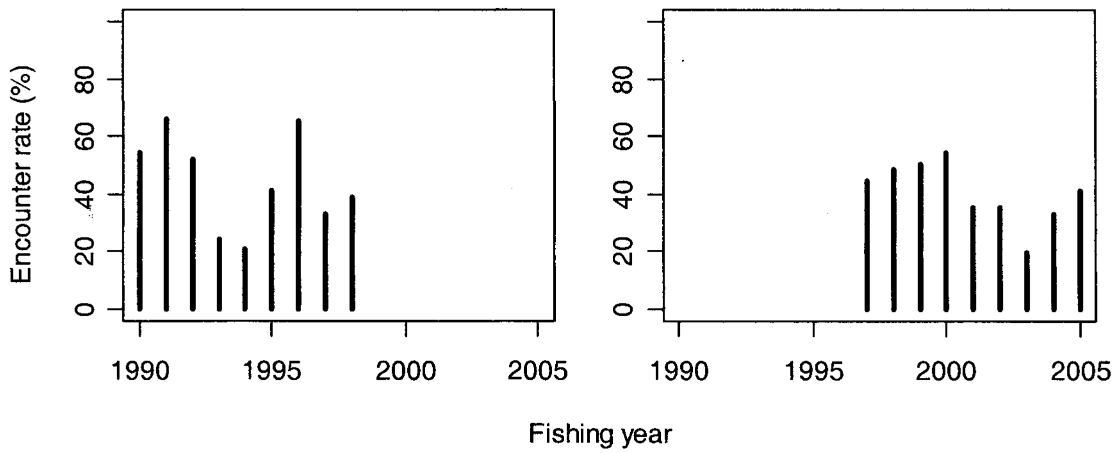

Figure 5: Annual encounter rate (proportion of non-zero catch tows of blue mackerel) for the early series (left) and for the late series (right). Year 1990 refers to fishing year 1989–90, etc.

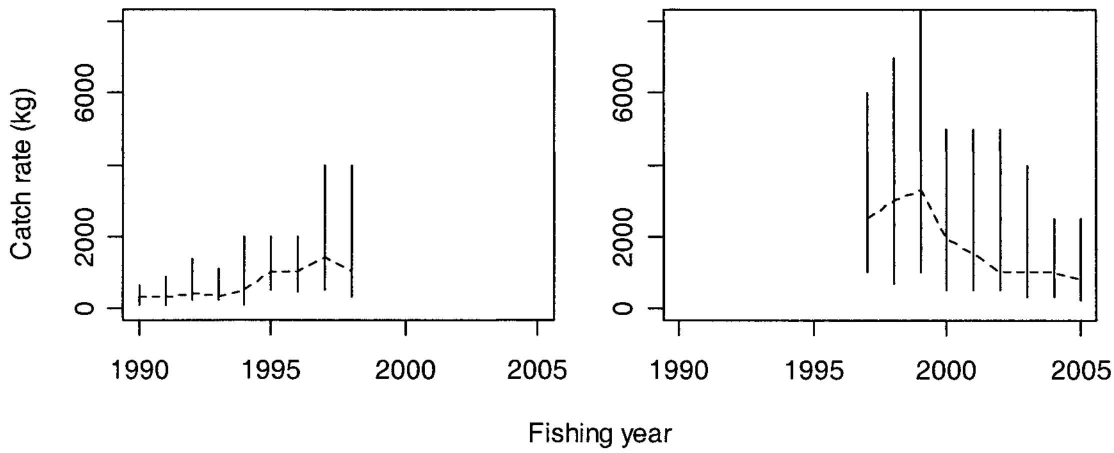

Figure 6: Annual catch rate (kg/tow, for non-zero catch tows of blue mackerel) for the early series (left) and for the late series (right). The dotted lines represent the median. The vertical lines extend to the lower and upper quantile. Year 1990 refers to fishing year 1989–90, etc.

3.2.3 CPUE indices

Standardised CPUE indices (including the component indices for the binomial and lognormal parts of the model) for the early and late time series are given in Table 17 and plotted in Figures 7 and 8. Stepwise selection of the variables is summarised in Table 18. The predicted catch rates by selected explanatory variables are shown in Figures 9 and 10. Diagnostic plots are shown in Figure 11. They were examined to assess the model fit.

For the early time series, the binomial and lognormal indices exhibited similar fluctuations, implying that when the probabilities of obtaining any blue mackerel catches were small (or high), the catch rates were also low (or high), the binomial indices showed a much steeper decline in 1992–93. The combined index decreased to a minimum in 1992–93, increased in 1994–95, and remained stable to 1997–98 (Figure 7).

For the late time series, the trends in the indices of the binomial and lognormal models were generally comparable except for the last two years. The combined index fluctuated through to 1999–2000, and then declined through to 2004–05 (Figure 8).

On average the binomial model explained 16–19% of deviance in the fitted data, and the lognormal model explained 29–32% of deviance (Table 18). For both early and late time series, the variables *statistical area*, *month*, and *vessel* were selected into the model.

The model predicted higher catch rates for Statistical Areas 034–036, 041, and 801 for the early time series, and Statistical Areas 041, 042, 045, and 801 for the late time series (Figures 9, 10). This appears to be consistent with the shift of fishing to the areas in the north in recent years. For both time series, the model predicted relatively low catch rates between August and December.

Vessel effect was also significant in the model for both time series. For the early time series, the predicted catch rates were higher for vessels 5, 8, and 11 (Figure 9), which had larger gross tonnage than the other vessels of the fleet (see Figure 4). For the late time series, the predicted catch rates were broadly similar among vessels 13–19 (Figure 10) as those vessels appeared to be identical in size and probably have similar fishing power (see Figure 4).

Plots of the predicted probabilities against observed non-zero probabilities of the binomial model for both data series were fairly close to straight lines indicating good fit, except that large variations were observed for the model fitted to the early time series (Figure 11). The quantile-quantile plots implied no serious violation of the model assumption (that the residual errors follow a normal distribution of constant variance), but indicated that there were still problems in predicting large values of catch rates for the early time series.

Table 17: Standardised CPUE indices from the binomial-lognormal model fitted to the early time series and the late time series. Year 1999 denotes fishing year 1998–99, etc.

Year	Vessels 1–12, 1990 to 1998			Vessels 13–19, 1997 to 2005		
	Binomial	Lognormal	Combined	Binomial	Lognormal	Combined
1990	1.00	1.00	1.00			
1991	1.17	1.43	1.51			
1992	0.65	1.65	1.39			
1993	0.30	1.04	0.57			
1994	0.27	1.20	0.61			
1995	0.65	1.63	1.37			
1996	1.01	1.31	1.31			
1997	0.65	1.75	1.47	1.00	1.00	1.00
1998	0.74	1.46	1.30	1.06	0.80	0.83
1999				1.29	0.98	1.14
2000				1.46	0.81	1.01
2001				1.14	0.62	0.67
2002				1.20	0.62	0.68
2003				0.52	0.34	0.22
2004				0.65	0.16	0.12
2005				0.94	0.14	0.14
2004				0.65	0.16	0.12
2005				0.94	0.14	0.14

Table 18: Variables included in order of importance in the stepwise regression of the binomial-lognormal model fitted to the early time series and the late time series. AIC stands for Akaike information criterion and R^2 denotes the percent of deviance explained.

CPUE dataset	Binomial			Lognormal		
	Variable	AIC	R^2	Variable	AIC	R^2
Early time series	*fishing year*	4982	0.070	*fishing year*	5938	0.089
1989–90 to 1997–98	*statistical area*	4 748	0.118	*vessel key*	5612	0.272
Vessels 1–12	*month*	4 494	0.169	*month*	5565	0.303
	vessel key	4 425	0.186	*statistical area*	5530	0.325
Late time series	*fishing year*	16 808	0.035	*fishing year*	19 384	0.109
1996–97 to 2004–05	*statistical area*	15 078	0.136	*statistical area*	18 614	0.245
Vessels 13–19	*month*	14 545	0.167	*month*	18 432	0.275
	vessel key	14 268	0.184	*vessel key*	18 297	0.297

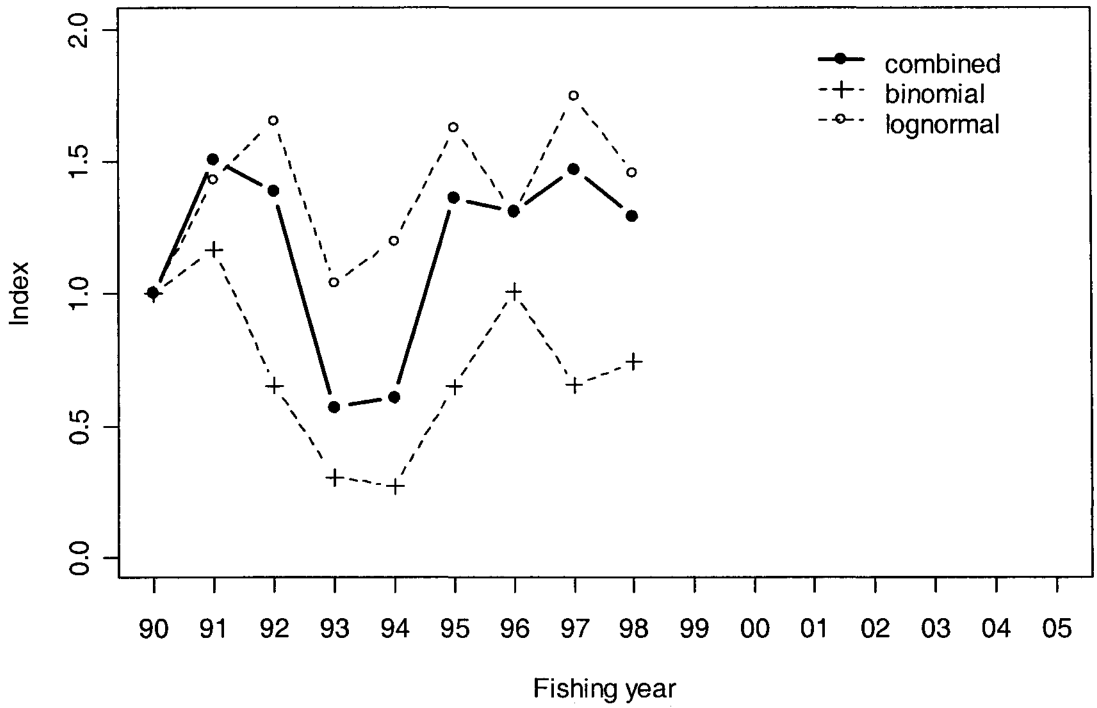

Figure 7: Standardised CPUE indices from the binomial-lognormal model fitted to the early time series. Year 99 denotes fishing year 1998–99, etc.

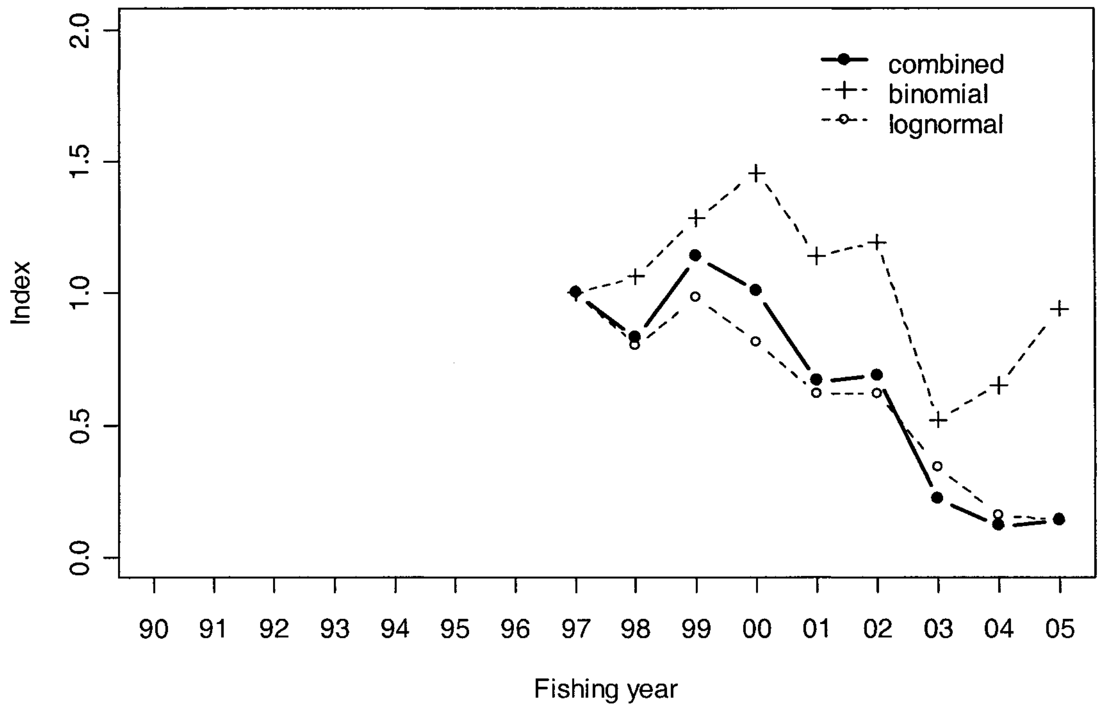

Figure 8: Standardised CPUE indices from the binomial-lognormal model fitted to the late time series. Year 99 denotes fishing year 1998–99, etc.

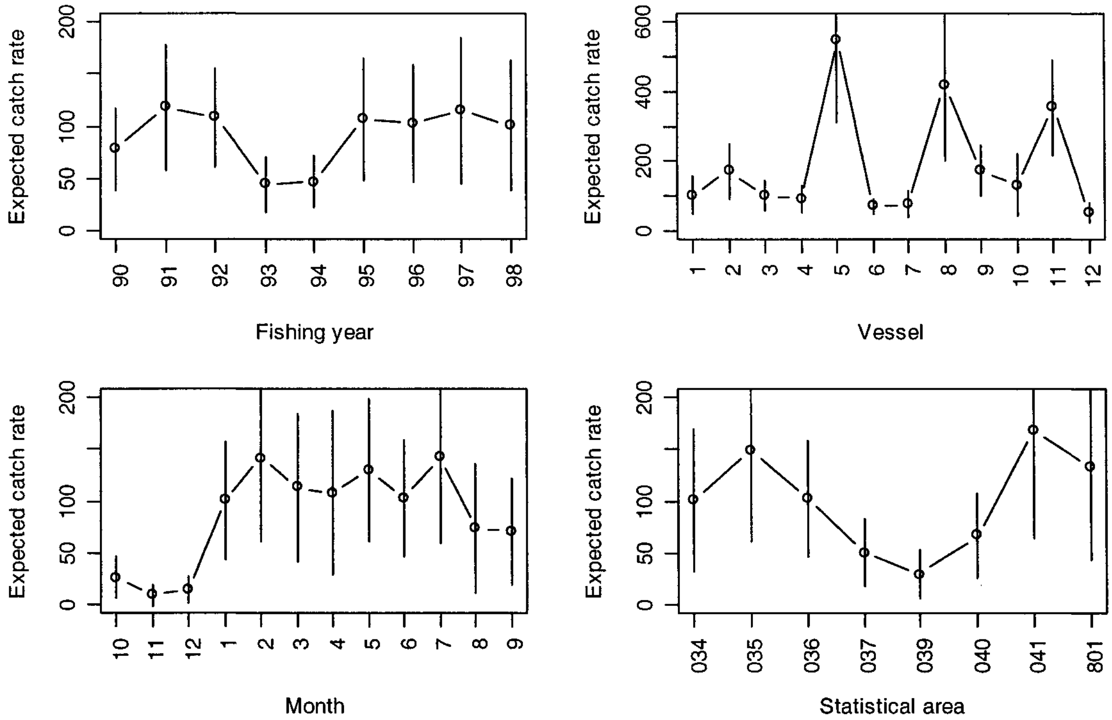

Figure 9: Expected catch rates (kg per hour) with standard error (vertical bars) of selected variables in the binomial-lognormal model for the early time series. Year 98 denotes fishing year 1997–98, etc.

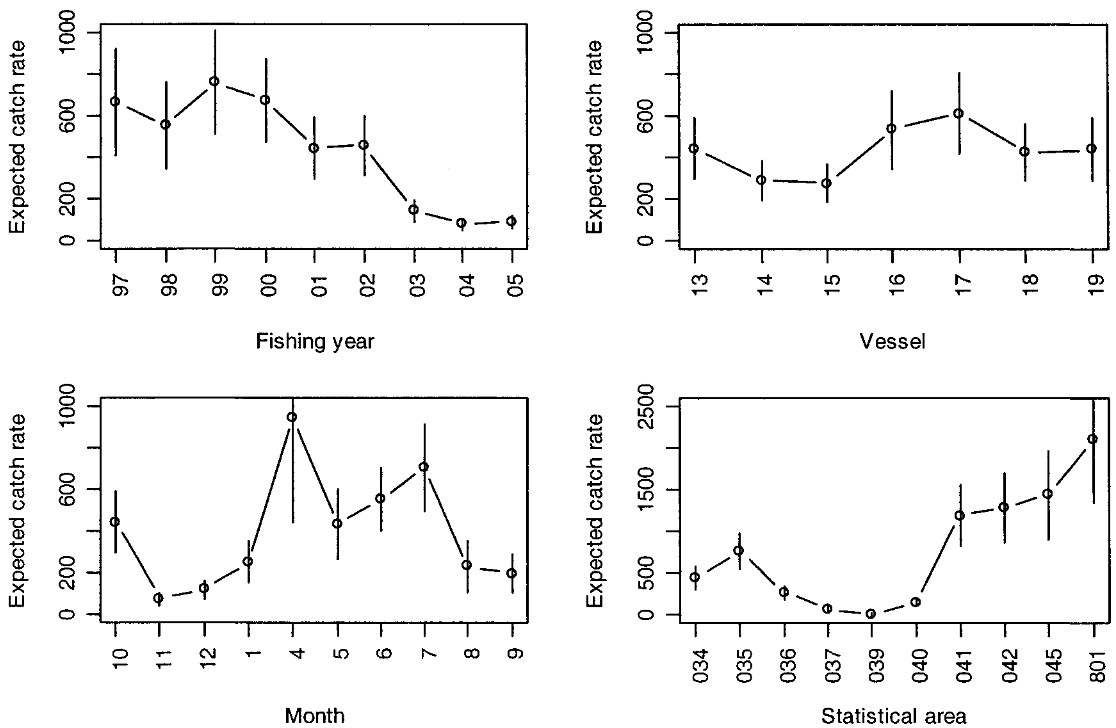

Figure 10: Expected catch rates (kg per hour) with standard error (vertical bars) of selected variables in the binomial-lognormal model for the late time series. Year 99 denotes fishing year 1998–99, etc.

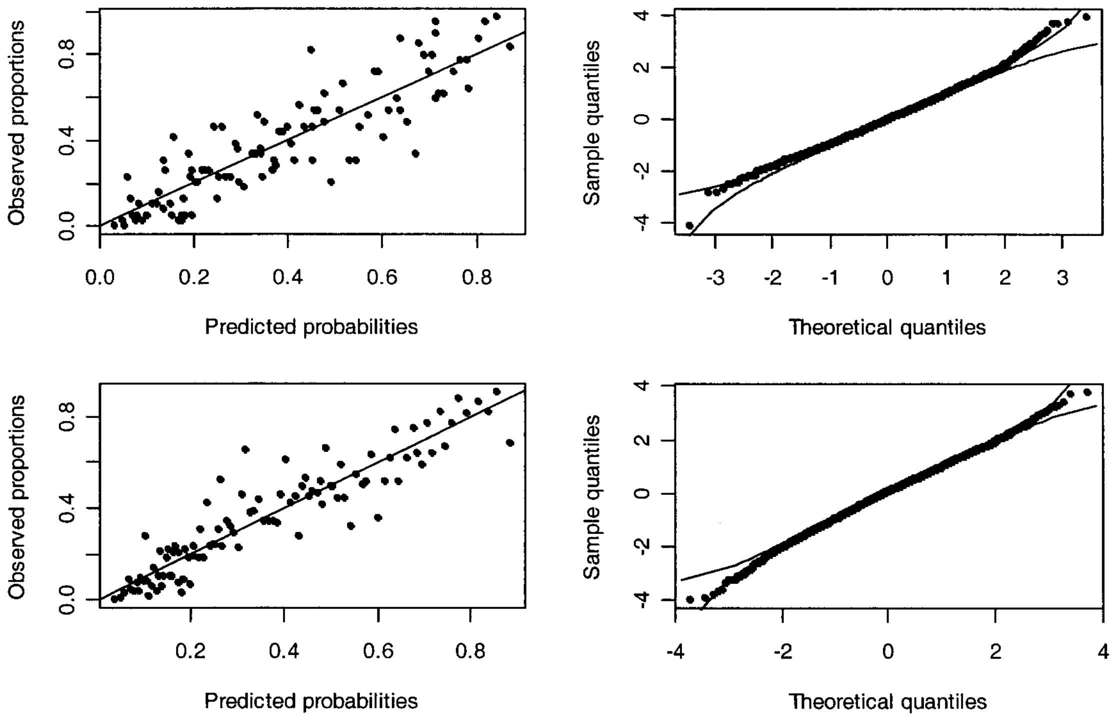

Figure 11: Plots of predicted probabilities of non-zero catches against observed proportions of non-zero catches for the binomial model (left), and normalised residuals against standard normal quantiles for the lognormal model (right) of the early time series (top panel) and the late time series (bottom panel),

4. DISCUSSION

The blue mackerel bycatch fishery in EMA 7 is mainly influenced by the midwater trawl jack mackerel target fishery. The CPUE standardisations were based on jack mackerel target tows and incorporated zero catches by use of a binomial-lognormal structure.

The analyses showed that the trends in the binomial indices were, in general, consistent with the lognormal indices. However, for the early time series, the combined index was largely determined by the more predominant trend in the proportion of zeros. The sharp decline in the indices for the early time series in 1992–93 and 1993–94 was mainly the result of the low encounter rate of blue mackerel in those two years. However, there was no evidence to show this was caused by a change in fishing behaviour in the midwater trawl jack mackerel target fishery. The high fraction of zeros in 1992–93 and 1993–94 could be due to a change in catchability, or to the relationship of blue mackerel catch to the catch of other species when recording the top five species on the TCEPR. This should be checked in future analyses using data from all available sources, including observer reports and landing data.

For the late time series, the median catch rate showed different trends among statistical area subgroups, and large interannual variation in catch rates for some statistical areas (Figure A9). The apparent spatial shift of fishing (from Statistical Area 034–037 to 040–042, 045, and 801) through the data series may also confound the interpretation of the CPUE indices. The PELWG suggested examining the possible *year*statistical area* interaction in the standardisation. Additional analysis showed that the *year*statistical area* interaction term would explain an additional 2% and 3% of deviance in the binomial and lognormal model, respectively. The combined index declined in Statistical Areas 034–036, remained stable in 037, 040, 042, and 045, and fluctuated in 041 and 801 (Figure A10)

Given the significant *year*statistical area* interactions estimated in the analysis and the large interannual variation in catch rates and CPUE in some areas, the PELWG agreed that it was premature to reach any conclusions about trends in abundance based on these indices.

5. ACKNOWLEDGMENTS

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Appendix A: Additional plots of EMA 7 descriptive and CPUE analyses

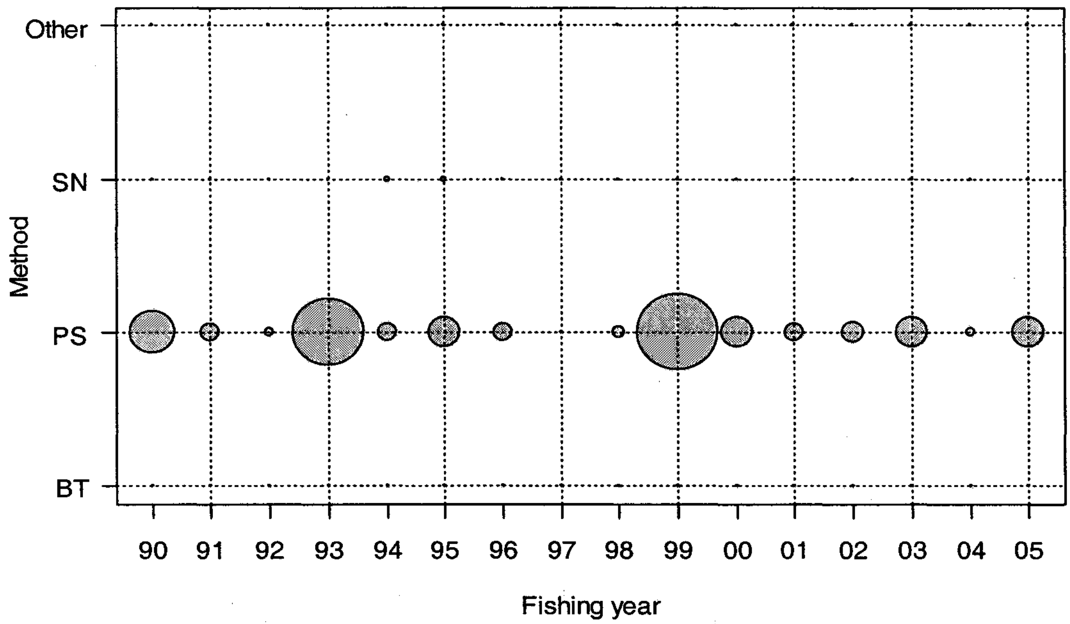

Figure A1: Annual estimated catch (t) by method as reported on CELR forms in EMA 7. The bubble area is proportional to the catch and the largest circle represents 3563 t. BT, bottom trawl; PS, purse-seine; SN, set net; Other, all other methods combined. Year 99 denotes 1998–99 fishing year, etc.

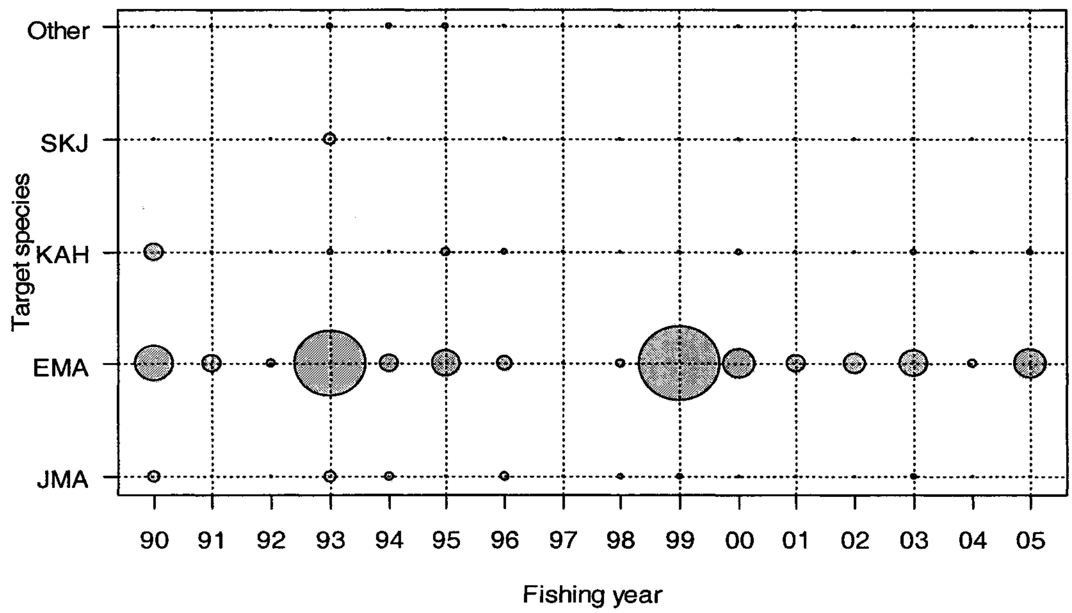

Figure A2: Annual estimated catch (t) by target species as reported on CELR forms in EMA 7. The bubble area is proportional to the catch and the largest circle represents 3563 t. JMA, jack mackerel; EMA, blue mackerel; KAH, kahawai; SKJ, skate; Other, all other species combined. Year 99 denotes 1998–99 fishing year, etc.

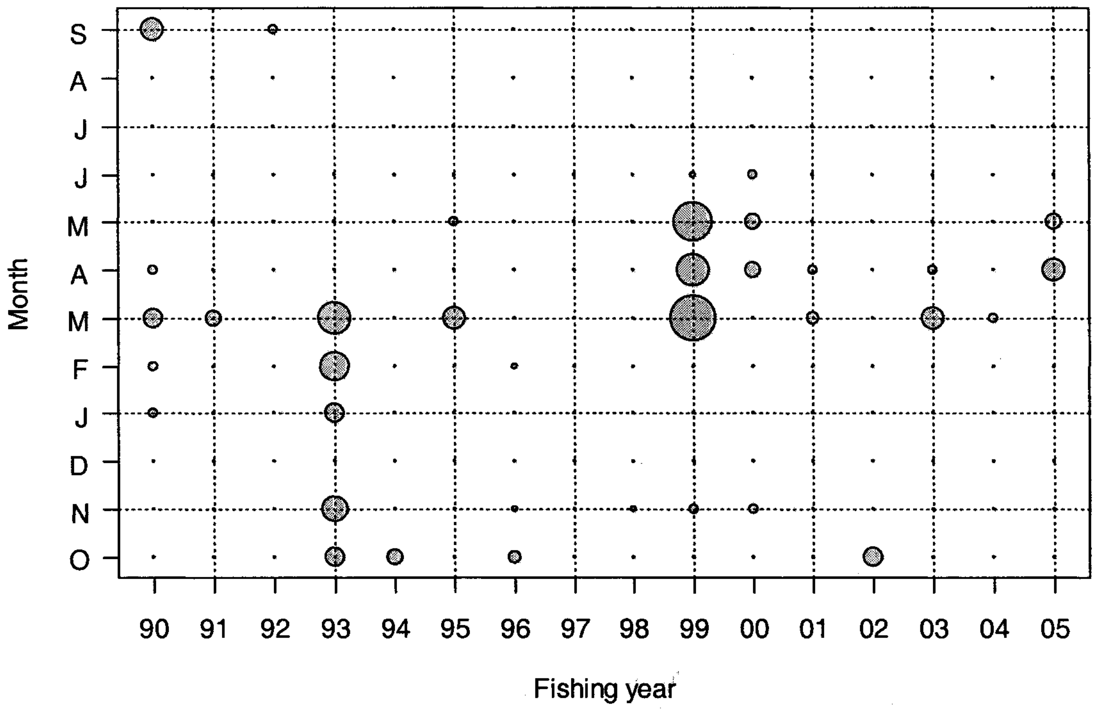

Figure A3: Annual estimated catch (t) by month for the CELR purse-seine target fishery in EMA 7. The bubble area is proportional to the catch and the largest circle represents 1474 t. Year 99 denotes 1998–99 fishing year, etc.

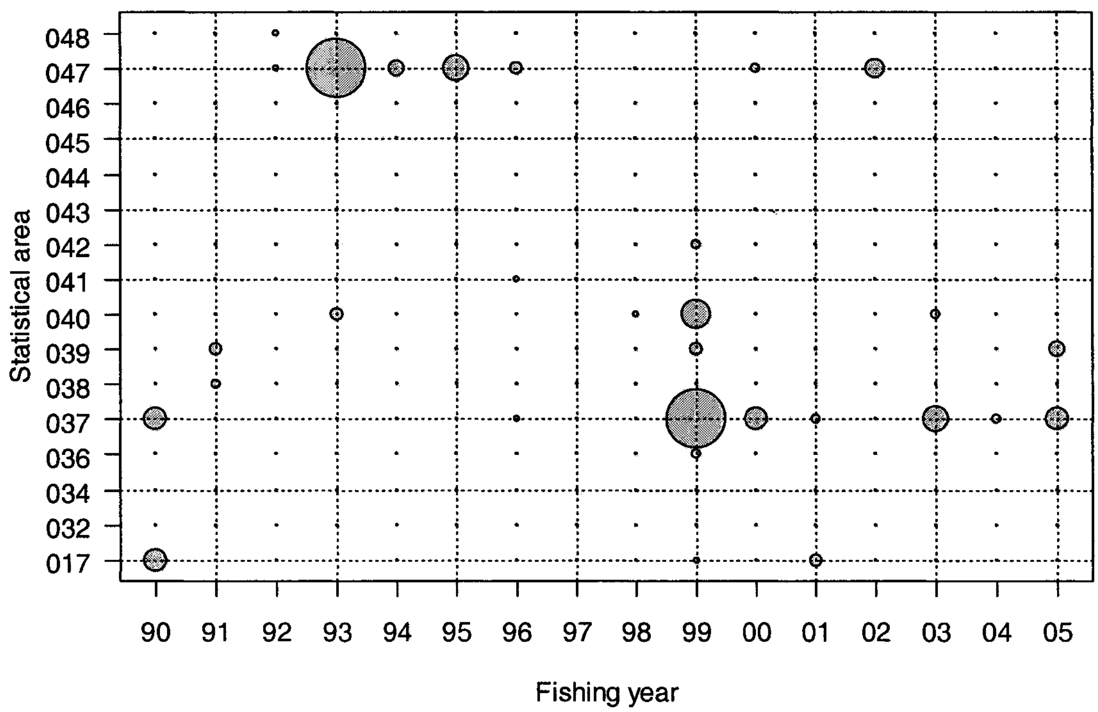

Figure A4: Annual estimated catch (t) by statistical area for the CELR purse-seine target fishery in EMA 7. The bubble area is proportional to the catch and the largest circle represents 2550 t. Year 99 denotes 1998–99 fishing year, etc.

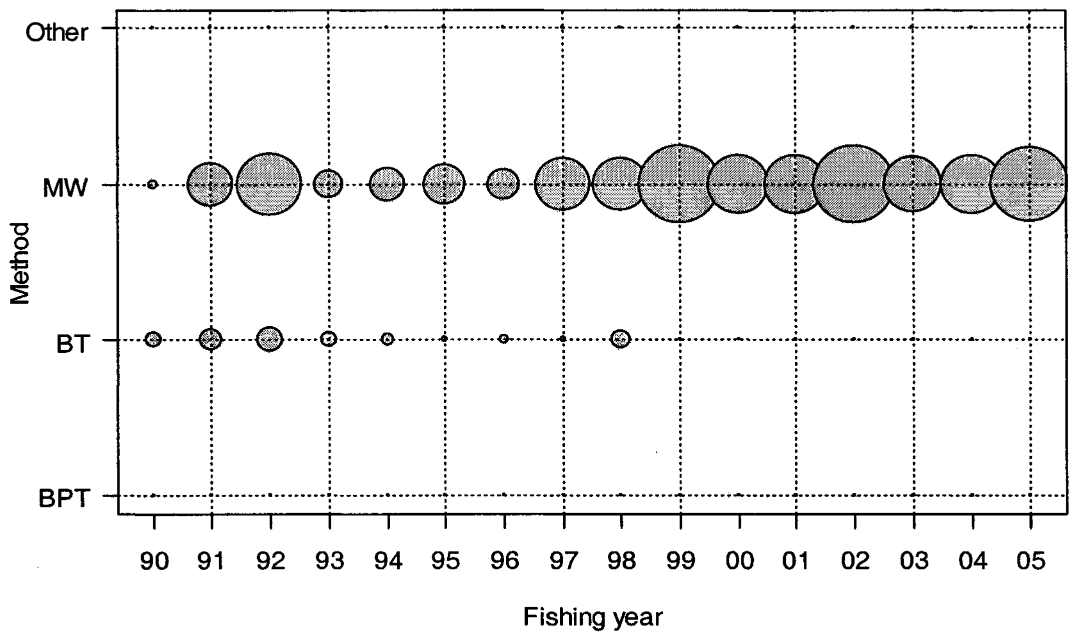

Figure A5: Annual estimated catch (t) by fishing method as reported on TCEPR forms in EMA 7. The bubble area is proportional to the catch and the largest circle represents 4193 t. BT, bottom trawl; BPT, bottom pair trawl; MW, midwater trawl; Other, all other methods combined. Year 99 denotes 1998–99 fishing year, etc.

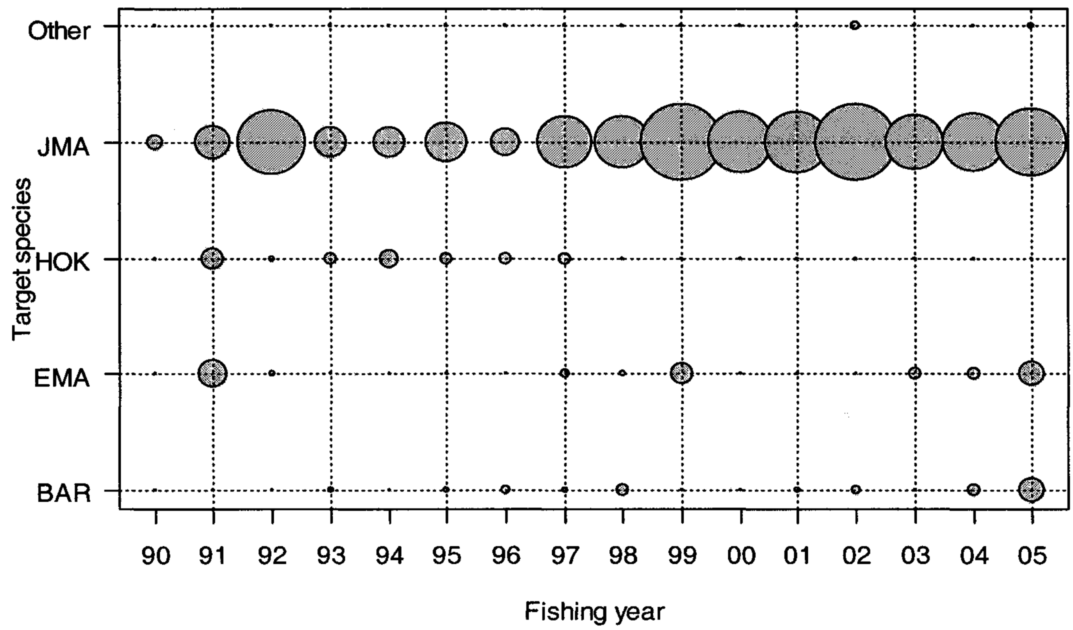

Figure A6: Annual estimated catch (t) by target species as reported on TCEPR forms in EMA 7. The bubble area is proportional to the catch and the largest circle represents 3900 t. JMA, jack mackerel; EMA, blue mackerel; HOK, hoki; BAR, barracouta; Other, all other species combined. Year 99 denotes 1998–99 fishing year, etc.

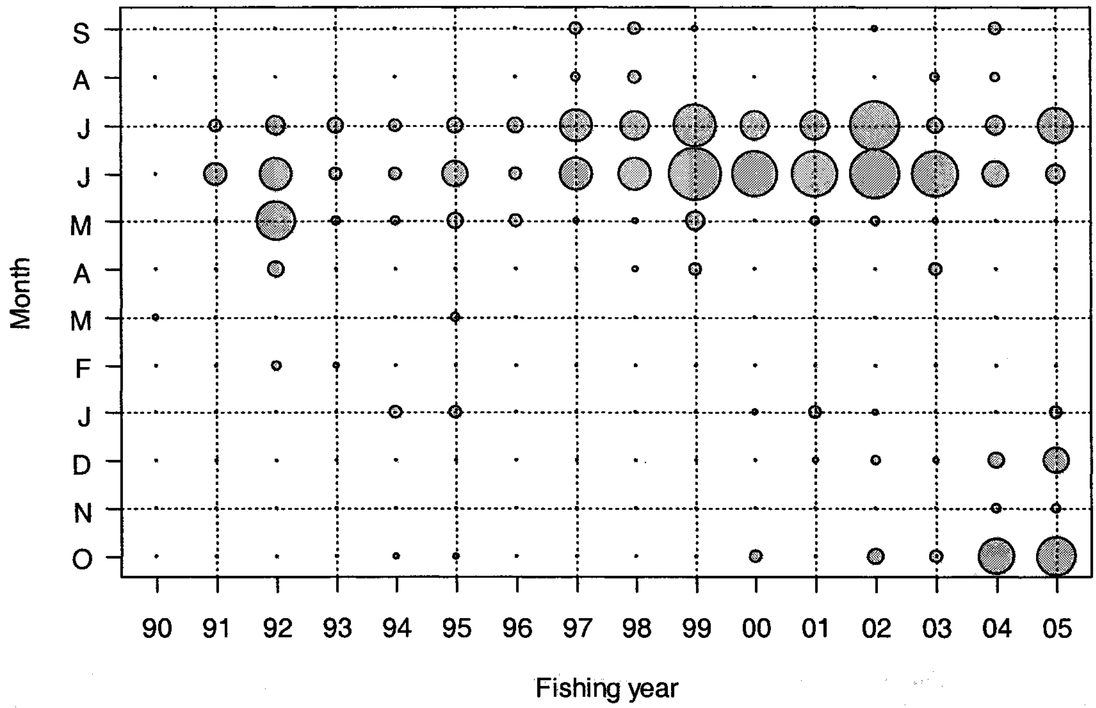

Figure A7: Annual estimated catch (t) by month for the TCEPR midwater trawl jack mackerel target fishery in EMA 7. The bubble area is proportional to the catch and the largest circle represents 2143 t. Year 99 denotes 1998–99 fishing year, etc.

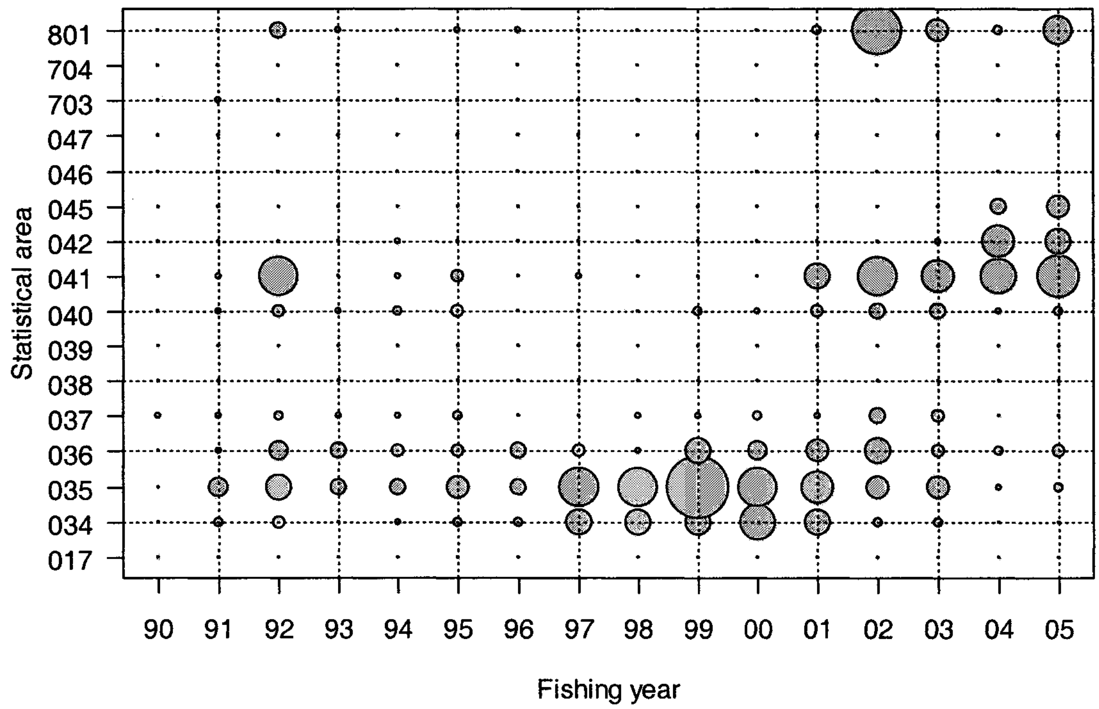

Figure A8: Annual estimated catch (t) by statistical area for the TCEPR midwater trawl jack mackerel target fishery in EMA 7. The bubble area is proportional to the catch and the largest circle represents 2864 t. Year 99 denotes 1998–99 fishing year, etc.

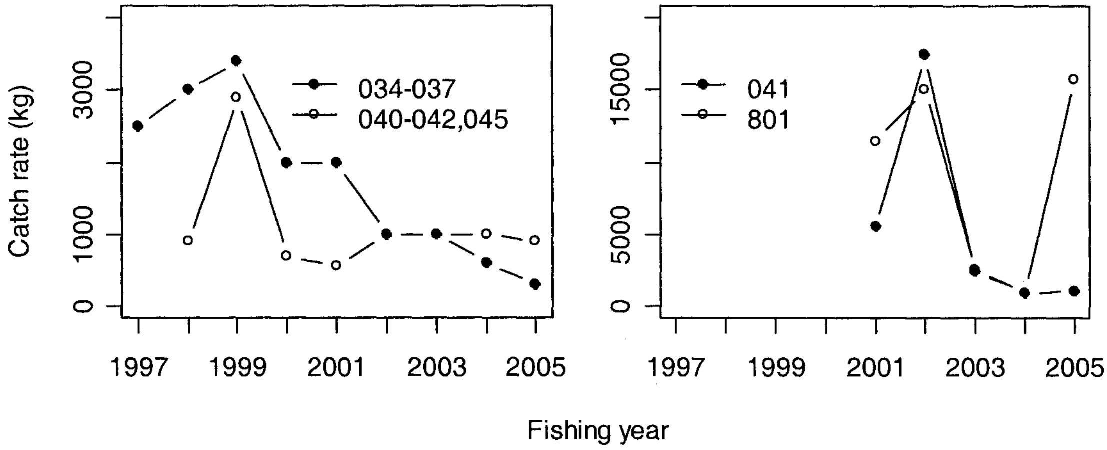

Figure A9: Median estimated catch rate (kg/tow) in Statistical Areas 034–037 and 040–042, 045 (left), and Statistical Areas 041 and 081 (right), for the late time series. Year 1997 denotes 1997–98 fishing year, etc.

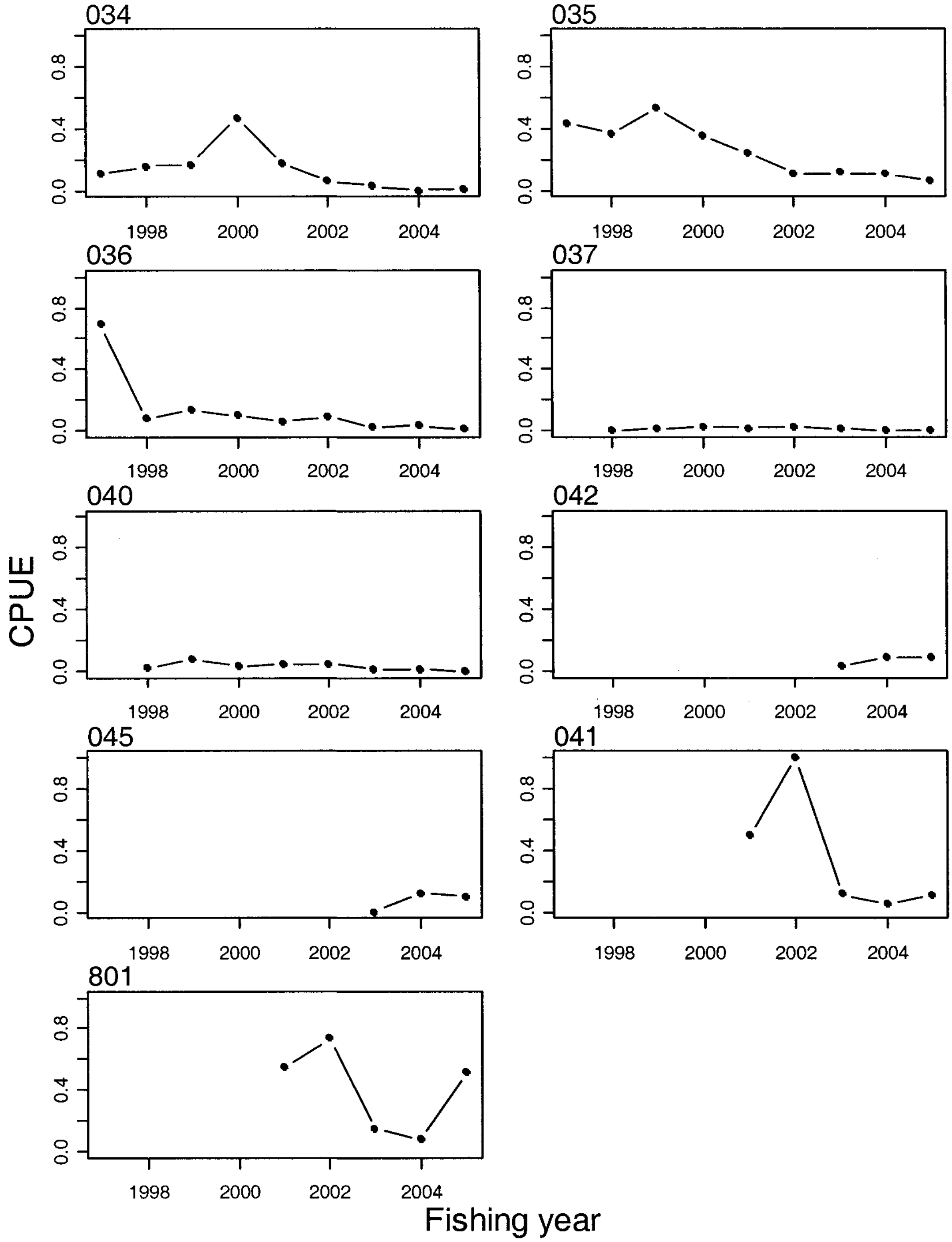

Figure A10: Combined CPUE indices calculated for each statistical area from the binomial-lognormal model with an additional *year*statistical area* interaction term for the late time series.