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K. D. Field
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K. D. Field[1]
M. R. Clark[2]

[1]NIWA
PO Box 109 695
Newmarket
Auckland

[2]NIWA
PO Box 14 901
Wellington

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EXECUTIVE SUMMARY

Field, K.D; Clark, M.R. (2001). Catch-per-unit-effort (CPUE) analysis and stock assessment for black cardinalfish (*Epigonus telescopus*) in QMA 2.

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1) A fishery for black cardinalfish developed in QMA 2 in 1981. Catch and effort summaries have been compiled for the New Zealand fishery using data from the Ministry of Fisheries Quota Management System.

2) Reported catches increased from several hundred tonnes in the first few years of the fishery to over 1500 t in 1986–87. Catches peaked at almost 3500 t in 1990–91, before decreasing to levels around 2000 t. In the last 2 years, catches have been about 1200 t. Most of the catch is taken as the target species, but in recent years up to 50% has occurred as a bycatch of the orange roughy fishery.

3) Standardised CPUE indices have been calculated. A regression analysis was applied to three sets of catch-effort data: raw CPUE, standardised analysis of success rate, and standardised analysis of the catch rates when fishing was successful. Indices from the latter two models were also combined. All these indices were restricted to the bottom trawl target cardinalfish fishery.

4) The main variables identified in the models as having a significant effect on CPUE were fishing year and fishing area. Fishing success in catching cardinalfish in a tow was relatively constant over the period examined. The catch rate of successful trawls showed a strong decline to 1993–94, and a fairly flat trend since then. The model explained only about 18% of variance in CPUE.

5) Stock assessment has been carried out using the CPUE combined index as a measure of relative abundance in a deterministic stock reduction model. Virgin biomass was estimated to be between 26 000 and 32 000 t. Current stock size is 4000 to 10 000 t, which is 15–30% of B_0. Estimates of MCY, CAY, and MAY were of the order of 200–500 t.

1. INTRODUCTION

Several species of *Epigonus* are widely distributed in New Zealand waters (Paulin et al. 1989), but only black cardinalfish (*E. telescopus*) reaches a marketable size and is found in commercial concentrations. It occurs throughout the New Zealand EEZ at depths of 300–1100 m, mostly in very mobile schools up to 150 m off the bottom over hills and rough ground. Black cardinalfish have been caught since 1981 by research and commercial vessels, initially as a bycatch of target trawling for other high value species (Field et al. 1997). The preferred depth range of schools (600–900 m) overlaps the upper end of the depth range of orange roughy (*Hoplostethus atlanticus*) and the lower end of alfonsino (*Beryx splendens*) and bluenose (*Hyperoglyphe antarctica*). The exploitation of these species from 1986 resulted in the development of the major cardinalfish fishery in QMA 2 (Table 1).

Black cardinalfish was introduced into the Quota Management System (QMS) on 1 October 1998. The TAC for QMA 2 was set at 2303 t and has remained unchanged. There is no known current recreational fishery for cardinalfish, and no quantitative information on the current level of Maori customary take.

The research reported in this document was part of a study conducted by NIWA for the Ministry of Fisheries under contract CDL9801.The objectives of CDL9801 reported on in this document are as follows.

2. To investigate the use of both standardised and unstandardised analyses of commercial catch and effort data as a relative abundance index for cardinalfish in QMA 2.

3. To develop a stock assessment model and undertake a stock assessment of cardinalfish in QMA 2, including estimating biomass and sustainable yield, if a relative abundance index is available from objective 1.

Results relevant to other objectives, principally estimation of age, growth, and mortality parameters were reported by Tracey et al. (2000).

2. THE DATA

For the purposes of this study QMA 2 was defined as statistical areas 011, 012, 013, 014, 015, 016, 201, 202, 203, 204, and 205. All records for these statistical areas that targeted and/or caught cardinalfish (reported either as the general cardinalfish code CDL, or the specific black cardinalfish code EPT) were extracted from the Catch, Effort and Landing Returns (CELR) and Trawl Catch, Effort and Processing Returns (TCEPR). Most of the estimated catch of cardinalfish (over 80% in 8 of the 11 years) was reported on the TCEPR database, i.e., catch and effort reported by individual tow (Table 2). As many more variables are available for inclusion in a CPUE analysis from the TCEPR format than the CELR format, we decided to include only TCEPR data in the analyses that follow.

Data were also extracted from the Inshore and Deepwater Fisheries Statistics Unit databases to cover the years 1982–83 to 1987–88. Unfortunately, the extent of errors in these data, combined with the lack of reporting of target species, made it impossible to incorporate these data in this study.

The following changes and deletions were made to the dataset. When a record reported EPT as the target species, the target was converted to CDL. Records were deleted from the dataset if they had missing values in any of the following fields: nation, target, method, wingspread, headline height, end latitude, end longitude, groundrope depth, bottom depth, vessel speed, CDL catch (113 records). The attribute *year vessel built* had 708 records with missing values, but rather than delete these records from the dataset, the attribute itself was not included in any of the analyses presented here. All variables were also checked for outliers and records deleted when values were outside reasonable

ranges for the field that could not readily be corrected: 75 records with wingspread given as 0 m; 6 records with bottom depth less than 250 m; 1 record with groundrope depth greater than 1600 m; 4 records with vessel speed greater than 7 knots; and 38 records with tow duration greater than 10 hours. The attribute *wingspread* had a very high proportion of records reporting unrealistically wide values. It is most likely (but we cannot be totally sure) the width of the doorspread was written down by mistake. Hence, the attribute wingspread was also not included in the analyses.

A small proportion (6%) of tows catching and/or targeting cardinalfish reported using midwater trawl gear. These 267 tows were not used in the analysis. All but a few tows were carried out by vessels registered to New Zealand. Russian vessels reported 13 tows for cardinalfish, but these few data were excluded from the analysis.

A known but unquantified source of mortality for cardinalfish has been the discarding at sea of this species while target fishing for higher value quota species (Annala et. al. 2000). This study has not incorporated any adjustments to catch levels for these discards.

3. FISHERY DESCRIPTION

The geographical distribution of cardinalfish catch and effort in QMA 2 has been associated with the development of orange roughy fisheries (Tables 3, 4, Figure 1). Areas of high catch and catch rates occur off East Cape, Tuaheni High (east of Gisborne), Ritchie Banks (Hawke Bay), and further south off the Wairarapa coast. Tows targeting and/or catching cardinalfish were first centred around the Ritchie Banks and Tuaheni High in areas 013 and 204, and tows were not reported in areas 011 and 102 until 1993–94, which coincides with the development of the East Cape orange roughy fishery.

Catch rates have decreased in recent years (Figure 1), and the total annual catch has also dropped in all statistical areas except 204 (Table 4), where the catch has been maintained by a doubling of the effort (Table 3). The seasonal distribution of both effort and catch has varied considerably over time (Tables 5, 6). All periods of the year have at some stage seen high effort and catches, with no apparent trends in the timing of the fishery.

Table 7 shows the annual number of tows, and Table 8 the annual catch, of cardinalfish, by target species. Of the fisheries targeting species at the shallow end of the cardinalfish range, only alfonsino (BYX) has contributed frequent and significant (70–200 t) annual catches of cardinalfish. At the deeper end of the cardinalfish range, from 80 to 200 tows targeting orange roughy reported a catch of cardinalfish each year. From 1989–90 to 1992–93 the annual catch of cardinalfish from these tows was relatively stable at about 350 t. In 1993–94 there was a very large catch (1400 t) associated with the development of the East Cape orange roughy fishery. After this catches steadily declined.

The distribution of the fishery specifically targeting cardinalfish has generally been similar to the overall distribution of catch (Figure 2). However, in several years effort was much more restricted than the catch. Although cardinalfish was occasionally the stated target on the Ritchie Banks in the early-mid 1990s, most of the fishing occurred on the Tuaheni High. The target fishery was more evenly spread between East Cape, Tuaheni, and the Ritchie Banks from 1995–96 to 1998–99. In 1997–98 there were few tows (< 50) on the Tuaheni High, and a small catch.

4. CPUE ANALYSES

Three sets of CPUE indices were calculated to indicate changes in stock size of cardinalfish. They were the raw (unstandardised) CPUE for cardinalfish in both the target cardinalfish and target orange roughy fisheries, standardised analysis of success rate (a binomial model), and standardised analysis of the catch rates when fishing was successful (a general linear model). Indices from the latter two models were also used to calculate a combined index (after Vignaux 1997).

The standardised CPUE analyses described below were carried out for tows that met the following criteria:

- were reported on the TCEPR catch-effort database
- were in statistical areas 011, 012, 013, 014, 015, 016, 201, 202, 203, 204, or 205
- targeted black cardinalfish (target = CDL or EPT)
- used a bottom trawl (method = BT)
- were reported by a vessel registered to New Zealand (nation = NZL)

This resulted in a dataset of 2073 tows for 35 vessels.

4.1 Unstandardised CPUE index

Unstandardised CPUE indices (t per tow) were calculated for the bottom trawl fisheries in QMA 2 that targeted cardinalfish and orange roughy (Table 9, Figure 3). Indices were calculated by fishing year, as the total catch of cardinalfish divided by the total number of tows. In the target cardinalfish fishery, i.e., all tows which reported targeting CDL, the index peaked at 6.5 t per tow in 1990–91 and declined steadily to 1.8 t per tow in 1995–96 and remained fairly flat through 1998–99. For those tows which were successful (i.e., targeted *and* caught CDL) there was a similar pattern with a steady decline from a peak of 14 t per tow in 1990–91 to 3.4 t per tow in 1995–96. The catch rate of cardinalfish from tows that targeted orange roughy followed a different pattern, being essentially flat between 1989–90 to 1992–93, peaking at 8 t per tow in 1993–94 when the East Cape orange roughy fishery opened, and then falling to 1.4 t per tow in 1998–99. The changes in the geographical distribution, and level of fishing effort (number of tows), between years means the total unstandardised data may not be directly comparable over time. Hence, although unstandardised CPUE is thought to track general changes in abundance, it may not be a precise index.

4.2 Standardised CPUE analysis

The analysis of success rate and catch rate were each standardised using a stepwise multiple regression technique (Vignaux 1994) to remove the effects of other explanatory (predictor) variables. The success rate analysis used a binomial model (Vignaux 1997) in which predictor variables were regressed against a successful (denoted as 1) or unsuccessful (denoted as 0) tow. A tow was considered unsuccessful if it had reported targeting cardinalfish *and* reported no catch of cardinalfish. Only the top five species caught by weight are reported in the catch-effort data, so an unsuccessful tow does not necessarily mean that no cardinalfish were caught. The catch rate analysis used a log-linear model in which the predictor variables were regressed against log(tonnes per tow) for all tows which reported targeting *and* catching cardinalfish. Catch per tow was chosen as the measure of CPUE because cardinalfish aggregate in schools that are generally caught by trawling briefly across the tops of hills and rough ground. In these situations the length of the tow in time or distance is not a relevant measure of effort.

Predictor variables used in the analyses are described in Table 10. In the first iteration for each analysis, log(CPUE) was regressed against each of the variables in turn to find the variable that explained the most variation (i.e., had the highest multiple regression coefficient, R^2). This variable was included in the model. At iteration 2, log(CPUE) was regressed against the new model plus each of the other variables in turn to find the next most significant variable. First order interactions were introduced only if *both* variables had been chosen by the model as having explanatory power on their own. This process was continued and variables were included in the models if they improved the explanatory power of the model by more than 0.5%.

A comparison of predictor variables included by the models is given in Table 11. The final R^2 for the log-linear model of successful tows was 17.4%. The relative year effects from each of the models and the combined indices are given in Table 12 and Figure 4. The index of success rate estimated by the binomial model is essentially flat, i.e., tows targeting cardinalfish are about as likely to catch a cardinalfish in 1989–90 as in 1998–99. The index of catch rates of the successful tows, estimated by the log-linear model, has shown a substantial decline. The combined index of success and catch rates declined rapidly between 1989–90 and 1993–94 to only 16% of the 1989–90 peak. From 1993–94 to 1998–99 the combined index fluctuated between 10 and 23% of peak values.

5. ESTIMATION OF BIOMASS

A deterministic stock reduction analysis technique (after Francis 1990) was used to estimate virgin (B_0) and current ($B_{1999\text{–}2000}$, mid-season 1999–2000) biomass. Biological parameters used were those given in Table 13 (largely from Tracey et al. 2000). The catches used in the model were the reported landings for QMA 2 given in Table 1. Catches in 1999–2000 and 2000–01 were assumed to be equal to the current TACC of 2303 t. The slope parameters for the maturity ogive (S_r, S_m) were derived from a probit analysis of length at maturity (authors' unpublished data).

The abundance estimates used in the stock reduction analysis were the combined CPUE indices of the target cardinalfish fishery given in Table 12. All estimates were used as indices of relative abundance. They were assumed to have a c.v. of 30%, and this was constant across all years. Model structure considers both sexes together, and involves natural mortality occurring before fishing mortality. Confidence intervals for B_0 were derived from bootstrap analysis.

The stock reduction analysis was run four times with different values of age at recruitment (A_r) and maturity (A_m), and natural mortality (M) to test the sensitivity of biomass estimates to these variables. The "base case" series was with $A_r = A_m = 45$ years and $M = 0.034$ as given in Table 13. The three alternative series considered combinations of $A_r = A_m = 35$ years (a value derived from a probit analysis of length at maturity, converted to age, authors' unpublished data) and $M = 0.05$ (an arbitrary value).

The model estimates of virgin and current biomass for the base case and alternative options are given in Table 14. Virgin biomass for all four options is in the range 23 000 to 33 000 t, and current biomass ranges from 10 to 32% of virgin. The lower estimates of current biomass are about the same as the current TAC of 2303 t. Population trajectories for the base case and scaled index values are given in Figure 5.

6. YIELD ESTIMATES

Yield estimates were calculated for the biomass range, B_{min}, to the upper 95% confidence limit for B_0 (Table 15). Maximum Constant Yield (MCY) and Current Annual Yield (CAY) were estimated using the simulation method of Francis (1992) with the biological parameters of Table 13 (and with the alternative $A_r = A_m = 35$ years). By this method, the long-term MCY is 1.13% (1.10%) of B_0, and under continued fishing at this level the mean biomass is 51.4% (52.3%) of B_0. Where the mid-season $B_{1999\text{–}2000}$ was estimated to be less than 20% of B_0, the MCY was adjusted by MCY = MCY*$B_{1999\text{–}2000}$/(0.2B_0) (after Francis 1992).

The exploitation rate associated with CAY, E_{CAY}, is 0.053 (0.048). This was applied to beginning of season biomass (less natural mortality) for 2000–01. The mean catch, MAY, when fishing at $E = 0.053$ (0.048) is 1.55% (1.40%) B_0, and the mean biomass, B_{MAY}, is 28.55% (28.5%) B_0. All these estimates are sensitive to assumed values of natural mortality and steepness (see tables 7 and 9 of Annala (1995), pp. 179–180).

Yield estimates for the base case and three alternative options are given in Table 15. For the base case, the range of MCY is 220–360 t, CAY 180–510 t, and MAY 400–500 t. All these estimates are less than 25% of the current TACC. The effect of lowering the ages at recruitment and maturity to 35 years is to slightly reduce all yield estimates, while increasing natural mortality to 0.05 lowers yield estimates by 20–30%.

7. DISCUSSION

This is the first assessment of a cardinalfish stock using a population model. The model results indicate that fishing levels to date in QMA 2 have had a significant impact on the biomass. Stock reduction estimates of current biomass as a percentage of virgin biomass are between 10 and 30%, while the point estimates of current biomass are for some options as low as the current TAC. Historic annual catch levels and the current TAC are more than 10 times higher than the estimates of MCY.

The biological parameters used in the model are uncertain. Tracey et al. (2000) reported high longevity and slow growth, but noted that age estimates were unvalidated. The low productivity, reflected in low estimates of yield relative to virgin biomass, are directly related to age and growth parameter estimates.

The catch and effort data used in the analysis were complicated by the mixed-fishery nature of much of the catch. The number of trawls available for the analysis was generally less than 500 per year. Many of the data records had incomplete or incorrect fields which limited the inclusion of some variables. The modelled changes in stock size do not follow CPUE changes well, although a similar pattern of a very steep decline followed by an ongoing period of low indices is common in CPUE estimates for orange roughy (e.g., Field & Clark 1996).

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Table 1: Reported landings (t) of black cardinalfish by QMA and fishing year (1 October to 30 September) from 1982–83 to 1998–99. The data in this table through 1994–95 is the "best estimate" of landings from Field et. al (1997, p. 3). Data since 1995–96 are based on catch and effort returns. –, no data; ET, outside the EEZ.

	QMA										
Year	1	2	3	4	5	6	7	8	9	ET	Total
1982–83	–	76	<1	<1	–	–	<1	–	–	–	78
1983–84	–	212	7	<1	–	–	<1	–	–	–	220
1984–85	<1	189	341	<1	–	–	1	–	–	–	532
1985–86	<1	238	50	3	2	–	<1	–	45	–	292
1986–87	1	1 738	72	2	<1	<1	<1	–	–	–	1 814
1987–88	3	1 556	28	1	3	–	2	<1	<1	–	1 638
1988–89	305	1 434	57	4	–	–	2	–	–	2	1 800
1989–90	613	1 718	20	18	–	–	15	–	–	<1	2 385
1990–91	233	3 473	598	1	4	–	1	<1	–	–	4 311
1991–92	7	1 652	146	3	<1	2	11	–	–	17	1 838
1992–93	23	1 550	519	2	<1	–	2	–	–	270	2 366
1993–94	364	2 310	277	10	5	–	6	–	–	829	3 801
1994–95	1 162	2 207	51	7	1	<1	51	–	<1	231	3 710
1995–96	1 418	2 621	57	4	10	–	26	–	–	340	4 490
1996–97	2 001	1 910	100	7	–	–	27	–	–	522	4 567
1997–98	995	1 176	40	351	–	–	76	–	108	405	2 743
1998–99	24	1 268	181	41	–	<1	16	<1	<1	390	1 921

Table 2: Summary of estimated catches (t) of cardinalfish by catch-effort data form type, and the percentage of reported landings represented by the TCEPR data, in QMA 2 from 1988–89 to 1998–99.

Fishing year	CELR	TCEPR	Total	% TCEPR	% TCEPR of reported landings
1988–89	20	121	141	86	8
1989–90	1 457	651	2 108	31	38
1990–91	1 136	2 208	3 344	66	64
1991–92	164	1 234	1 398	88	75
1992–93	62	1 331	1 393	96	86
1993–94	72	2 366	2 438	97	102
1994–95	224	1 859	2 083	89	84
1995–96	177	1 696	1 873	91	65
1996–97	287	1 520	1 807	84	80
1997–98	63	966	1 029	94	82
1998–99	183	1 017	1 200	85	80

Table 3: Summary of effort (number of tows) reported on TCEPRs that caught and/or targeted cardinalfish in the bottom trawl fishery by statistical area in QMA 2 from 1988–89 to 1998–99.

Fishing year	011	012	013	014	015	016	201	202	203	204	205
1988–89	0	0	0	1	5	0	0	0	0	17	0
1989–90	0	0	66	3	16	0	1	0	0	80	0
1990–91	0	0	203	0	26	0	0	0	0	136	1
1991–92	0	3	55	0	58	0	0	0	1	119	0
1992–93	0	1	73	2	64	0	0	0	0	123	0
1993–94	53	24	133	7	133	3	0	1	1	111	1
1994–95	90	54	112	0	78	5	22	2	1	90	0
1995–96	167	87	174	0	100	17	2	0	3	121	0
1996–97	59	42	198	1	108	6	14	0	0	125	0
1997–98	95	44	55	8	35	2	11	0	0	242	3
1998–99	106	44	147	29	61	1	13	0	0	271	0

Table 4: Summary of estimated catches (t) of cardinalfish reported on TCEPRs in the bottom trawl fishery by statistical area in QMA 2 from 1988–89 to 1998–99.

Fishing year	011	012	013	014	015	016	201	202	203	204	205
1988–89	–	–	–	20	40	–	–	–	–	61	–
1989–90	–	–	358	2	57	–	<1	–	–	221	–
1990–91	–	–	1 685	–	45	–	–	–	–	432	1
1991–92	–	2	467	<1	180	–	–	–	<1	339	–
1992–93	–	25	372	<1	223	–	–	–	–	569	–
1993–94	155	131	1 120	67	370	2	–	17	<1	441	1
1994–95	470	113	685	–	317	2	1	<1	7	260	–
1995–96	503	291	517	–	79	6	<1	–	21	277	–
1996–97	68	64	642	1	312	9	21	–	–	376	–
1997–98	113	92	12	5	24	2	6	–	–	668	<1
1998–99	133	102	316	10	102	4	3	–	–	336	–

Table 5: Summary of effort (number of tows) reported on TCEPRs that caught and/or targeted cardinalfish in the target cardinalfish bottom trawl fishery by month in QMA 2 from 1988–89 to 1998–99.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1988–89	0	0	0	0	0	0	0	0	0	0	0	17
1989–90	4	1	0	20	14	2	31	0	0	0	11	10
1990–91	4	24	27	45	11	2	53	52	10	0	6	17
1991–92	4	7	9	57	21	17	14	11	0	1	2	0
1992–93	3	1	21	14	34	62	15	10	0	1	6	9
1993–94	25	44	20	59	4	19	15	30	35	2	11	9
1994–95	47	40	25	37	10	25	17	12	7	2	15	19
1995–96	32	53	31	122	50	74	96	69	13	0	12	6
1996–97	28	48	18	16	29	52	22	105	53	21	12	19
1997–98	18	29	10	51	33	20	64	44	19	0	19	49
1998–99	1	8	5	39	21	27	77	60	17	11	72	116

Table 6: Summary of estimated catches (t) of cardinalfish reported on TCEPRs in the target cardinalfish bottom trawl fishery by month in QMA 2 from 1988–89 to 1998–99.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1988–89	–	–	–	–	–	–	–	–	–	–	–	41
1989–90	<1	12	–	88	41	<1	231	–	–	–	2	12
1990–91	<1	296	242	438	<1	1	386	158	<1	–	115	1
1991–92	1	27	26	425	52	17	2	85	–	20	<1	–
1992–93	<1	<1	104	78	113	344	10	92	–	<1	<1	<1
1993–94	137	125	68	226	21	61	17	31	58	<1	<1	<1
1994–95	292	59	1	67	<1	84	120	27	97	30	68	56
1995–96	67	104	54	231	63	72	220	111	61	–	<1	54
1996–97	76	66	30	17	30	81	47	338	92	117	0	31
1997–98	21	79	53	245	133	73	58	33	3	–	1	54
1998–99	0	8	75	3	30	3	196	107	1	31	121	109
Total	594	776	654	1 819	484	735	1 287	983	312	198	357	307

Table 7: Summary of effort (number of tows) reported on TCEPRs that caught and/or targeted cardinalfish in the bottom trawl fishery by target species in QMA 2 from 1988–89 to 1998–99. CDL, black cardinalfish; BNS, bluenose; BYX, alfonsino; HOK, hoki; OEO, oreo; ORH, orange roughy; SSO, smooth oreo; WWA, white warehou.

Fishing year	CDL	BNS	BYX	HOK	OEO	ORH	SSO	WWA
1988–89	17	0	0	0	0	6	0	0
1989–90	93	0	0	0	0	71	2	0
1990–91	251	0	6	11	0	98	0	0
1991–92	143	0	2	1	0	91	0	0
1992–93	176	0	4	0	0	83	0	0
1993–94	273	0	13	2	0	178	0	0
1994–95	256	2	22	2	0	172	0	0
1995–96	558	0	6	13	4	89	1	0
1996–97	423	6	20	16	8	80	0	0
1997–98	356	0	1	5	12	121	0	0
1998–99	453	0	1	2	0	215	0	1
Total	2 999	8	75	52	24	1 204	3	1

Table 8: Summary of estimated catches (t) of cardinalfish reported on TCEPRs in the bottom trawl fishery by target species in QMA 2 from 1988–89 to 1998–99. CDL, black cardinalfish; BNS, bluenose; BYX, alfonsino; HOK, hoki; OEO, oreo; ORH, orange roughy; SSO, smooth oreo; WWA, white warehou.

Fishing year	CDL	BNS	BYX	HOK	OEO	ORH	SSO	WWA
1988–89	41	–	–	–	–	80	–	–
1989–90	386	–	–	–	–	249	3	–
1990–91	1638	–	19	110	–	396	–	–
1991–92	655	–	1	5	–	326	–	–
1992–93	740	–	78	–	–	371	–	–
1993–94	745	–	115	23	–	1421	–	–
1994–95	902	3	195	<1	–	756	–	–
1995–96	1035	–	71	5	36	544	3	–
1996–97	926	25	126	71	66	280	–	–
1997–98	754	–	<1	3	19	145	–	–
1998–99	684	–	<1	4	–	312	–	6

Table 9: Comparison of number of tows and unstandardised CPUE (t pertow) of the cardinalfish bottom trawl fishery in QMA 2, for: all tows that targeted CDL; tows that targeted and caught CDL; and tows that targeted ORH and caught CDL.

Fishing	All target CDL tows		Successful target CDL tows		Target ORH with CDL catch	
year	*n*	t/tow	*n*	t/tow	*n*	t/tow
1989-90	93	4.15	50	7.72	71	3.51
1990-91	251	6.53	117	14.00	98	4.04
1991-92	143	4.58	54	12.13	91	3.58
1992-93	176	4.21	83	8.92	83	4.47
1993-94	273	2.73	94	7.93	178	7.98
1994-95	256	3.52	120	7.51	172	4.40
1995-96	549	1.85	303	3.42	89	6.11
1996-97	423	2.19	189	4.90	80	3.50
1997-98	356	2.12	180	4.19	121	1.20
1998-99	453	1.51	190	3.60	215	1.45

Table 10: Definitions of variables used for the standardised CPUE regression analyses. cat, categorical with number of categories; cont, continuous.

Variable	Type	Description
Fishing year	cat 11	fishing year (1 October to 30 September) of the tow
Month	cat 12	month that the tow took place in
Area	cat 11	statistical area that the tow took place in
Depth	cont	bottom depth at start of the tow
Speed	cont	speed of the vessel in knots during the tow
Vessel tonnage	cont	gross tonnage of the vessel
Vessel power	cont	power of the vessel in kilowatts
Vessel length	cont	overall length of the vessel in metres
Vessel breadth	cont	breadth of the vessel in metres
Vessel draught	cont	draught of the vessel in metres
Start time	cont	time at the start of the tow
End time	cont	time at the end of the tow
Start latitude	cont	latitude at the start of the tow
Start longitude	cont	longitude at the start of the tow

Table 11: Comparison of variables selected in the target cardinalfish fishery in QMA 2 regression models in the order in which they entered the model down to 0.5% improvement in the model.

Linear regression		Binomial regression	
Variable	% R^2	Variable	% improve
fishing year	7.47	fishing year	–
statistical area	9.04	month	0.76
vessel draught	10.55	statistical area	0.57
month	11.52		
vessel draught * month	15.64		
bottom depth	16.84		
tow end time	17.39		

Table 12: Comparison of total number of tows with unsuccessful tows (no CDL catch), and the linear, binomial, combined, and unstandardised (t/tow) indices for cardinalfish in the target cardinalfish fishery in QMA 2.

Fishing year	Total tows	Zero tows	P(zero)	Linear index	Binomial index	Combined index	Unstandardised index
1989–90	93	43	0.46	1.00	1.00	1.00	4.15
1990–91	251	134	0.53	0.86	1.31	0.75	6.53
1991–92	143	89	0.62	0.79	1.81	0.58	4.58
1992–93	176	93	0.53	0.42	1.14	0.40	4.21
1993–94	273	179	0.66	0.23	1.97	0.16	2.73
1994–95	256	136	0.53	0.24	1.11	0.23	3.52
1995–96	549	254	0.46	0.10	0.93	0.10	1:85
1996–97	423	234	0.55	0.16	1.31	0.14	2.19
1997–98	356	176	0.49	0.16	1.04	0.16	2.12
1998–99	453	263	0.58	0.22	1.44	0.18	1.51

Table 13: Biological parameters used in the estimation of biomass and yields in this assessment.

Parameter	Symbol	Both sexes
Natural mortality	M	0.034 yr^{-1}
Age of recruitment	A_r	45 yr
Gradual recruitment	S_r	13 yr
Age at maturity	A_m	45 yr
Gradual maturity	S_m	13 yr
von Bertalanffy parameters	L_∞	70.8 cm
	K	0.034 yr^{-1}
	t_0	–6.32
Length-weight parameters	a	2.7e-8
	b	2.87
Recruitment variability	σ_R	1.2
Recruitment steepness		0.75

Table 14: Biomass estimates (t). The ranges given correspond to B_{min} to the upper 95% confidence limit for B_0.

Series	B_0	$B_{current}$	$B_{current}/\%B_0$
A_m=A_r=45, M=0.034	26 000–32 200	3 943–10 170	15–32
A_m=A_r=35, M=0.034	26 600–32 800	3 962–10 196	15–31
A_m=A_r=45, M=0.05	22 600–25 900	2 370–5 696	11–22
A_m=A_r=35, M=0.05	23 300–26 700	2 387–5 823	10–22

Table 15: Yield estimates (t). The ranges given correspond to B_{min} to the upper 95% confidence limit for B_0. The long-term MCY is the MCY when the biomass is greater than 20%B_0; the MAY is the long-term average CAY.

Series	$MCY_{1999–2000}$	$MCY_{long\text{-}term}$	CAY	MAY
A_m=A_r=45, M=0.034	220–364	294–364	181–511	403–499
A_m=A_r=35, M=0.034	200–328	266–328	161–460	372–459
A_m=A_r=45, M=0.05	140–293	255–293	109–286	350–401
A_m=A_r=35, M=0.05	117–267	233–267	95–261	326–374

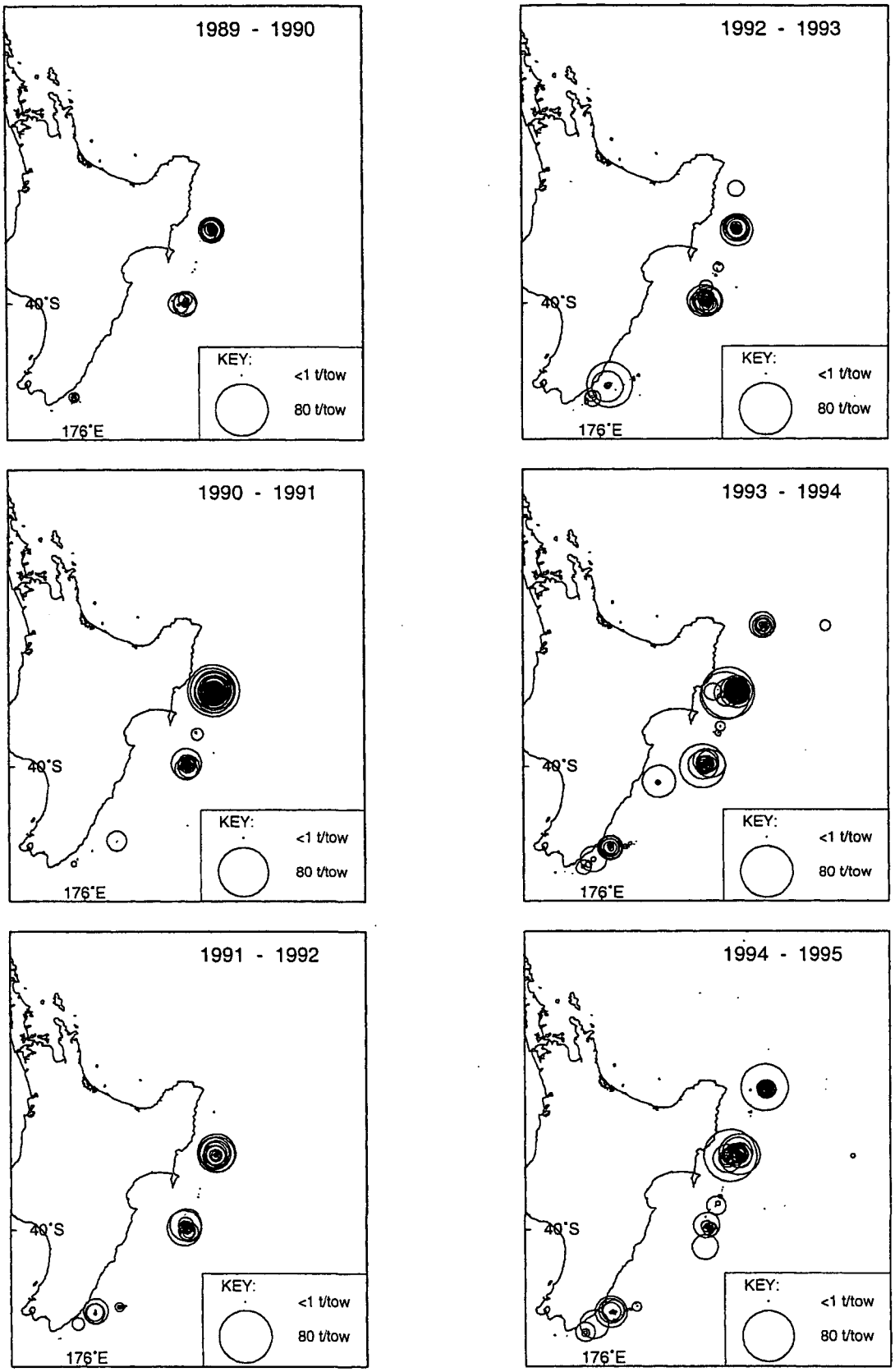

Figure 1: Unstandardised catch rates (t/tow) of cardinalfish for tows that caught and/or targeted CDL by bottom trawl in QMA 2.

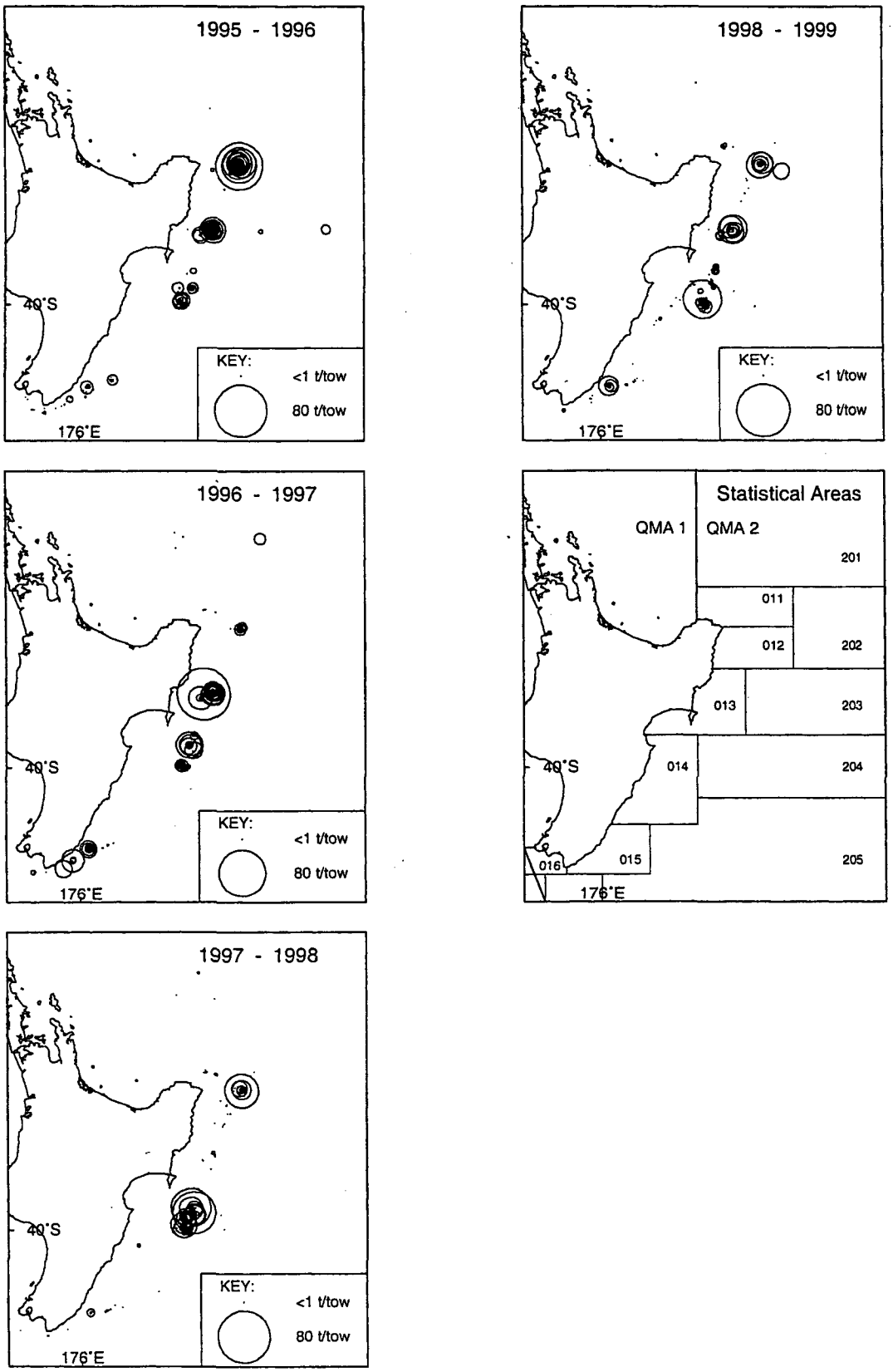

Figure 1 cont: Unstandardised catch rates (t/tow) of cardinalfish for tows that caught and/or targeted CDL by bottom trawl in QMA 2.

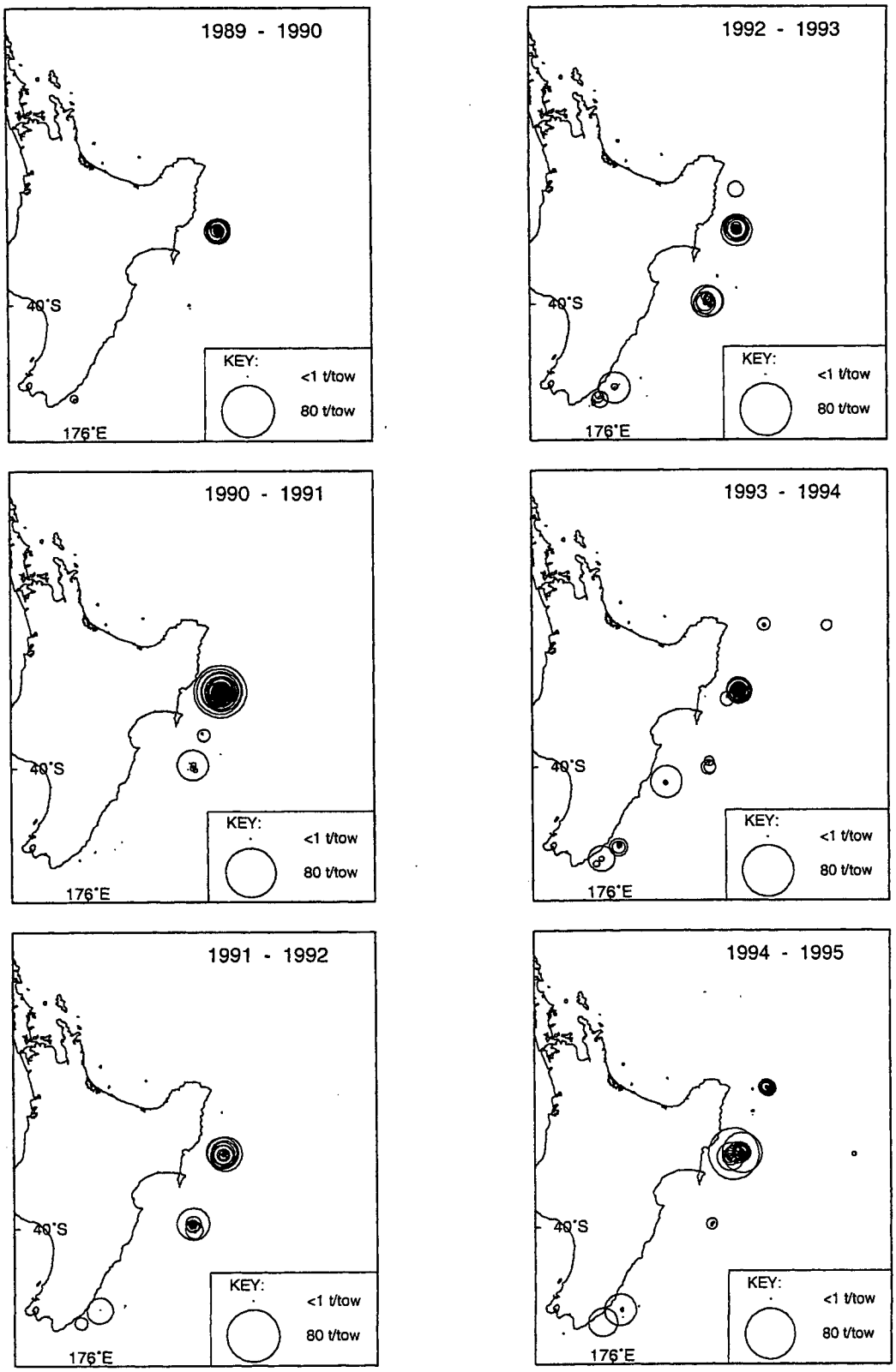

Figure 2: Unstandardised catch rates (t per tow) of cardinalfish for tows that targeted CDL by bottom trawl in QMA 2 from 1989–90 to 1998–99.

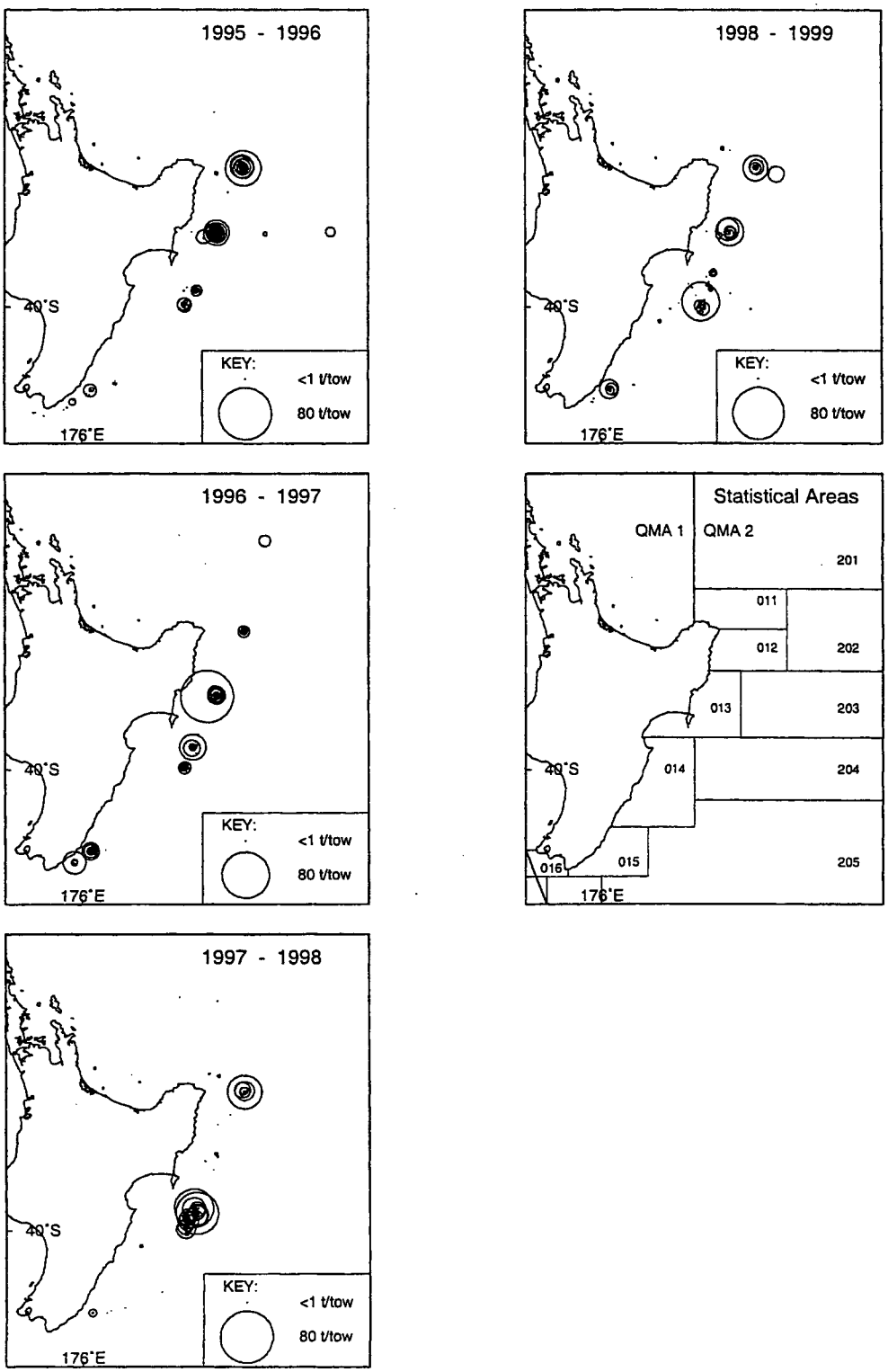

Figure 2 cont: Unstandardised catch rates (t per tow) of cardinalfish for tows that targeted CDL by bottom trawl in QMA 2 from 1989–90 to 1998–99.

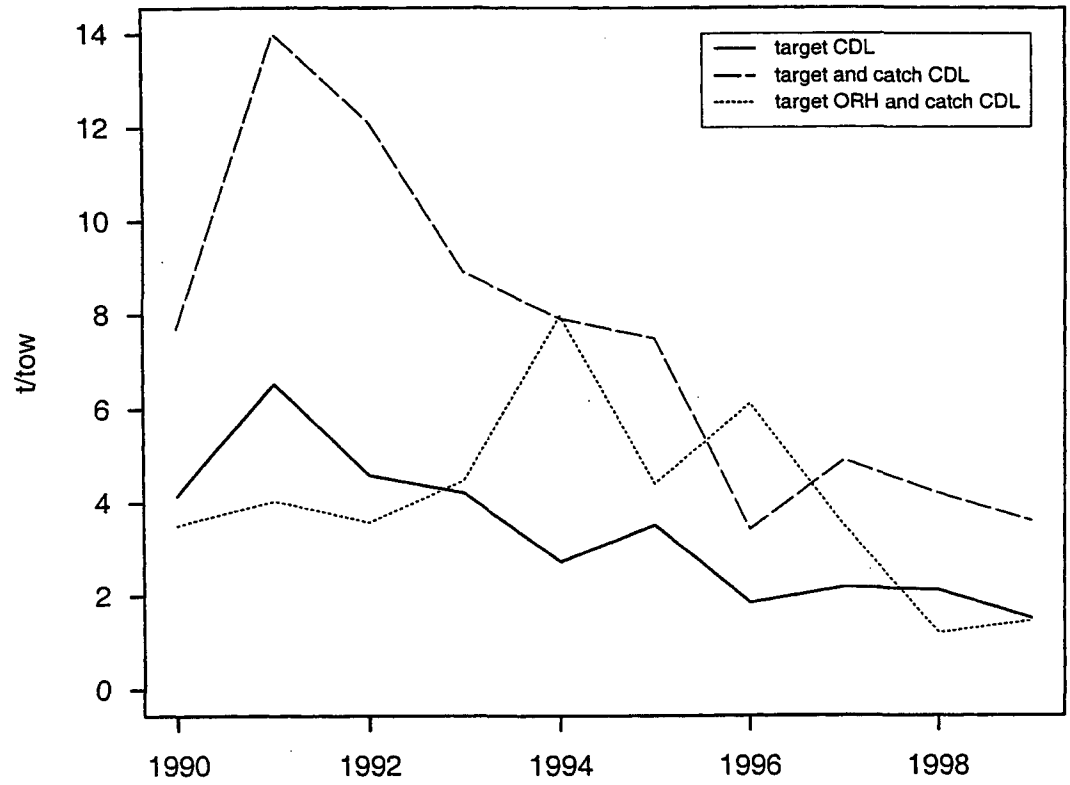

Figure 3: Unstandardised CPUE indices (t per tow) of cardinalfish in QMA 2.

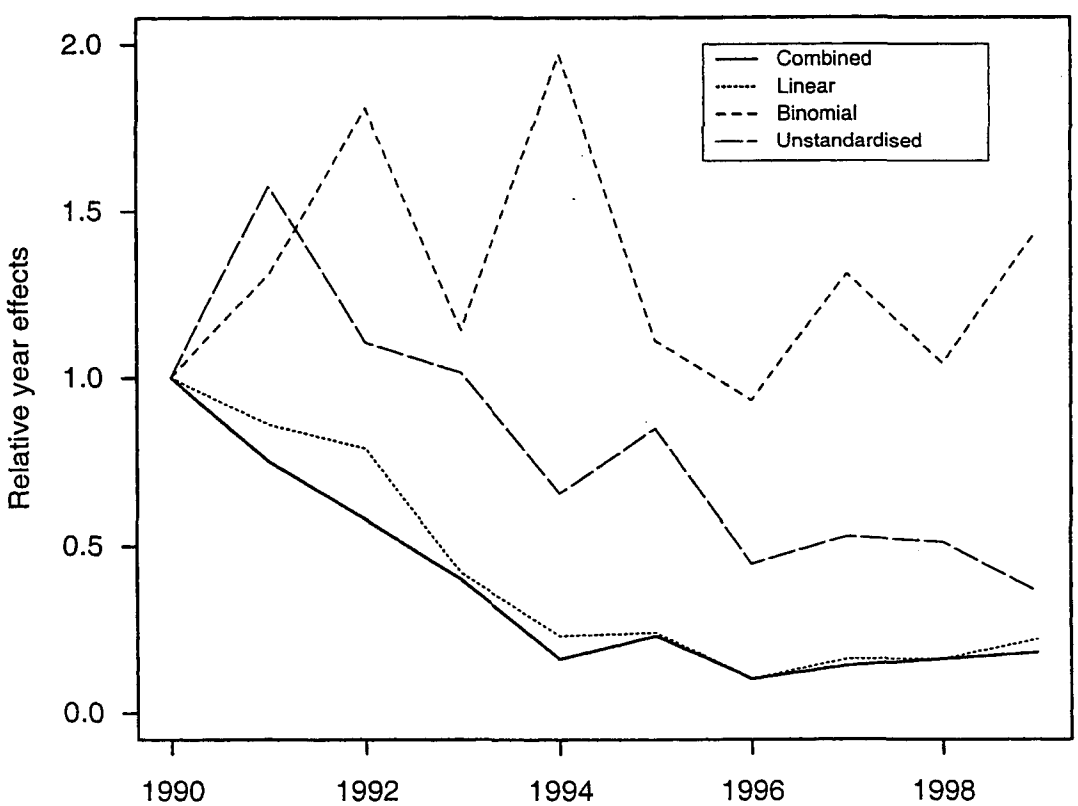

Figure 4: Comparison of relative year effects and unstandardised CPUE for the target CDL fishery in QMA 2.

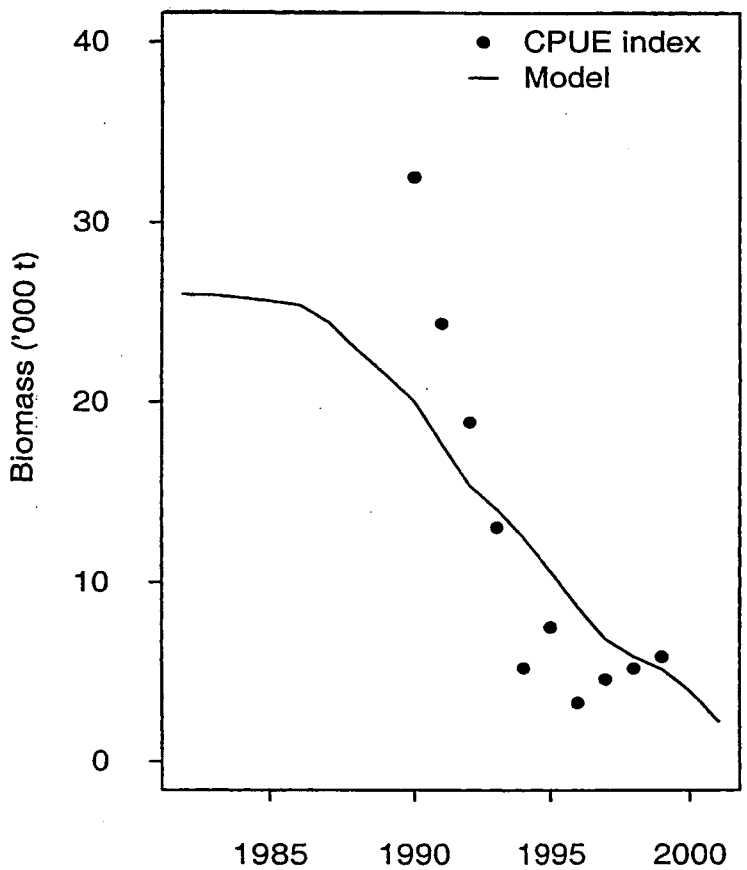

Figure 5: Biomass trajectory for cardinalfish in QMA 2. CPUE indices are for the target CDL bottom trawl fishery.