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EXECUTIVE SUMMARY

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This report updates descriptive analyses of commercial catch and effort data for all the main black cardinalfish fisheries in the New Zealand Exclusive Economic Zone (EEZ) from 1990–91 to the end of the 2007–08 fishing year. It also includes a description of one fishery outside the EEZ, on the northern Challenger Plateau and southern Lord Howe Rise. The distribution, estimated catch, effort, and unstandardised catch rate trends are described for each of nine subarea fisheries, and standardised catch per unit effort (CPUE) indices determined for the fishery in Quota Management Area 2.

The main fishery areas identified in previous analyses were still yielding catches of black cardinalfish, and no substantial new fishing areas were developed. Almost all fishing used bottom trawls, at depths of 470–980 m, and was focused on and around hill features, using short tows (less than 30 minutes). Historically, black cardinalfish was largely a bycatch in other deepwater fisheries, but after 2000–01 more than 75% of black cardinalfish were caught in targeted tows. Targeted fishing success was low, as at least half of the targeted tows failed to catch black cardinalfish. Total catches fluctuated, but overall showed a slow decline. Catches in 2007–08 were the lowest since 1990–91, at 1134 t, and took only 30.2% of the Total Allowable Commercial Catch limit. The largest fisheries continued to be off the east coast of the North Island (CDL 2), and in the Bay of Plenty (CDL 1).

Catches in the Kaikoura subarea increased in 2007–08 but remained relatively low. Recent catches in the Wairarapa subarea were relatively low. Catches in the east coast North Island and Bay of Plenty subareas were at their lowest level in 2007–08 since the fisheries developed, despite targeted effort being relatively high in the east coast North Island. The fishery in the Bay of Plenty had become more sporadic. The fishery outside the EEZ on North Challenger Plateau and Lord Howe Rise had effectively ceased.

Standardised CPUE indices for CDL 2 were estimated by fitting generalised linear models to CPUE, using a stepwise multiple regression technique. The predictor *fishing year* was forced into the models, and additional predictors included *vessel*, *target species*, *subarea*, *depth*, *distance from hill*, and *fishing day*. Binomial models explained 11.4–16% of the deviance in fishing success, and Gaussian models 7–20% of the deviance in the log of non-zero catch rate. Confidence intervals of the combined binomial and Gaussian models were estimated using a bootstrap technique. A single CPUE index for 1990–91 to 1997–98 indicated a decline of at least 50%. Three different CPUE indices for 1998–99 to 2007–08 indicated a decline of at least another 50%. However, the 95% confidence intervals for the year effects were high in all models (31–61%).

1. INTRODUCTION

Black cardinalfish (*Epigonus telescopus*, Risso 1810) are the only commercially exploited species of cardinalfish in New Zealand waters (MFish Science Group 2008). There are several species of cardinalfish in New Zealand waters, but commercial catches of other species are very rare (Dunn 2007).

The exploitation of black cardinalfish within the New Zealand EEZ started as a bycatch in the early 1980s, with a targeted fishery developing from the mid 1990s (Field et al. 1997, Dunn 2005, 2007). The species came into the Quota Management System (QMS) on 1 October 1998, and Total Allowable Commercial Catches (TACCs) were set for Quota Management Areas (QMAs) 2–8 (Figure 1). In the following year, TACCs were set for QMAs 1 and 9. No TACC has been set for QMA 10. The QMAs for black cardinalfish are referred to as CDL1 to CDL 10. There have been no scientific studies to determine the number or boundaries of black cardinalfish stocks in New Zealand waters.

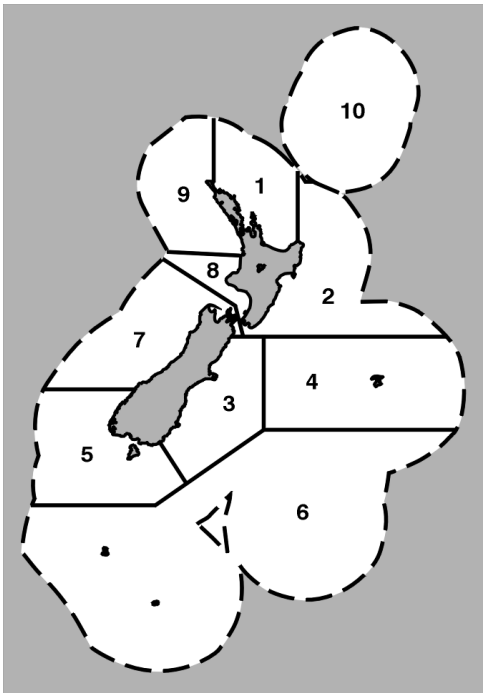

Figure 1: Location of Quota Management Areas (QMAs) for black cardinalfish within the New Zealand EEZ.

The focus of fishing effort for black cardinalfish has been on or near hills and other underwater features, with about 80% of the catch in 2004–05 taken on or near features (Dunn 2007). The largest black cardinalfish fisheries are to the east of the North Island, where black cardinalfish has been targeted, and also caught as a bycatch primarily in orange roughy, alfonsino, bluenose, and hoki target fisheries (Dunn 2007). It is likely that fishing effort on black cardinalfish is influenced by the TACCs on these other, more valuable fisheries (Dunn 2007).

There are no published fishery independent biomass indices for black cardinalfish, and stock assessments have therefore used standardised commercial catch per unit effort (CPUE) indices, assuming that these will index the stock biomass. The standardisation of CPUE has used generalised linear models (GLMs) to estimate the trend in CPUE by year, after removing effects due to other factors such as vessel, target species, and time of year. The first

standardised analysis of CPUE for black cardinalfish was by Field & Clark (2001), for the New Zealand (domestic) bottom trawl fishery targeting black cardinalfish in CDL 2. The most important predictor in the models after fishing year was statistical area, followed by vessel draught, month, depth, and time of day. The index showed a 90% decline in catch rate between 1989–90 and 1995–96, followed by a slight increase during 1996–97 to 1998–99. The subsequent stock assessment using this index was rejected by the MFish Deepwater Fisheries Assessment Working Group because the model biomass trajectory did not fit the CPUE index well (MFish Science Group 2008). Specifically, the CPUE index declined more rapidly than the model biomass trajectory (Field & Clark 2001).

Phillips (2002) completed the first analysis of standardised CPUE for CDL 1, using data where cardinalfish was caught and/or targeted, and concluded that CPUE was not a reliable index of abundance. This was due to a high variability in catch rates, and a small data set available. Nevertheless, the indices suggested CPUE in 2000–01 was about 20–40% of that in 1994–95, and Phillips concluded that the fishery needed to be monitored carefully.

The most recent analyses of CPUE was for CDL 2 (Dunn 2007), for the black cardinalfish target fishery, with a focus on short tows, and also a specific area (Tuaheni) known to be a 'hot-spot' for black cardinalfish catches and effort. The most important model predictors, after fishing year, included vessel, season, tow distance, depth, and subarea (which was an area around the 'nearest hill'). The indices showed a very steep initial decline in CPUE between 1990–91 and 1994–95, which was caused in part by the vessel and season predictors. Ignoring this initial steep decline, the CPUE indices still declined dramatically, with indices for 2004–05 being one–third or less of that 10 years earlier. However, Dunn (2007) noted an increase in the proportion of tows catching black cardinalfish after 1998–99, when black cardinalfish entered the QMS, which may have caused a bias. The data set at the time was not long enough to split into pre- and post-1998–99 indices. In addition, the focus on specific areas and short tows meant that the final indices described only a small proportion of the total black cardinalfish catch, and as a result the indices might not describe the overall stock abundance well. The CPUE indices were considered uncertain by the MFish Deepwater Fisheries Assessment Working Group, and not suitable for use in a stock assessment.

There have been no other studies to determine the status of New Zealand black cardinalfish stocks, and consequently the status of the stocks remains poorly known. The previous studies have all identified substantial declines in CPUE, but have not been able to provide an accepted estimate of sustainable yield. The only changes to the TACCs since they were introduced was for CDL 4 and CDL5, which were increased from 5 t to 66 t and 2 t to 22 t respectively from 1 October 2006.

The work described in this report was carried out under Ministry of Fisheries (MFish) project CDL200801 objective 1: "To update unstandardised and standardised catch per unit effort analyses for CDL 2, with the inclusion of data to the end of the 2007/08 fishing year." It includes an update of the descriptive analysis of Dunn (2005, 2007), with a focus on CDL 2, and includes the standardised analysis of CPUE for CDL 2.

2. METHODS

2.1 Data sources

Two data sets were used for analyses, extracted from the Ministry of Fisheries (MFish) Catch Effort Database. The first was used to describe the fisheries, and included all records where black cardinalfish was specified as targeted and/or caught on Trawl Catch Effort Processing Returns (TCP), Catch, Effort and Landing Returns (CEL), or Trawl Catch Effort Returns (TCE), and including the "high seas" versions of the TCP and CEL returns (HTC and HCE

forms respectively). A second data set was used to analyse catch per unit effort for the CDL 2 fishery, and included all TCP and TCE returns for the CDL 2 area where the depth fished was greater than 200 m. These data sets covered the fishing years 1990–91 to 2007–08. The data for the period before 1990–91 were analysed by Dunn (2005). The TCP and TCE returns gave tow-by-tow information, with location and estimated catch for each trawl. The CEL returns provided daily catch records with effort estimated as the number and total duration of tows in the day. CEL forms tended to be used by smaller inshore vessels, and larger deepwater vessels (over 28 m in length) were required to complete TCP forms. In addition, details of the corresponding vessel specifications were provided by MFish, and included a time series of records of vessel length, power, and tonnage.

2.2 Data grooming

Error checks were performed for the following data fields:

- Bottom depth (where more than 1300 m or less than 300 m)
- Effort depth (with respect to *bottom depth*)
- Position (for location, and where large differences in start and finish position)
- Trawl speed (where more than 7 kt or less than 1 kt)
- Duration (where more than 12 hours)
- Tow distance (where more than 30 nautical miles)
- Target species
- Vessel nationality (if none ever recorded then assumed to be Domestic)
- Time of day

Missing or erroneous values were replaced with imputed average values. As examples, (1) where depth was missing it was replaced with the mean depth from all other tows recorded within 1 n.mile of that tow position; (2) where tow length calculated using given positions was greater than 30 n.mile, and speed calculated from distance and duration was greater than 8 knots, the tow positions were replaced with the median values for that vessel and day (this would allocate the vessel to roughly the right area); (3) where tow speed appeared to be an error, it was replaced with the median tow speed for that vessel on that day. Records containing errors that could not be corrected were excluded from further analyses.

The distance between the tow location and the nearest known underwater feature was calculated. The tow location was the mid-point of the tow, or the start-point where the end positions were missing. The list of features included 840 known underwater pinnacles, hills and seamounts, most of which most were hills (elevations of 95–5070 m; A.Rowden, NIWA, pers.comm.).

A known but unquantified source of mortality for black cardinalfish has been the discarding at sea of this species while target fishing for higher value species (MFish Science Group 2008). This study has not incorporated any adjustments to catch levels for these discards.

2.3 Definition of fishery areas

In addition to MFish QMAs, this description of the fishery also uses areas described by Dunn (2005), which were as follows:

1. Kaikoura. The area between 172.9° E and 175.2° E, and between 41.7° S and 43.1° S. Catches from this area are included in QMA 2 and QMA 3.
2. Wairarapa. The area between 175.1° E and 177.3° E, and between 40.65° S and 42° S. Catches from this areas are included in QMA 2.

3. East Coast. Catches from this area are included in QMA 2.
    a. Ritchie Hill and the Rockgarden. The area bounded by points at 178.2° E 39.2° S, 177.8° E 40.2° S, 178.5° E 40.2°S and 178.9° E 39.2° S.
    b. Tuaheni High. The area between 178.35° E and 179° E, and between 38.6° S and 39.1° S.
    c. East Cape. The area between 178.4° E and 180°, and between 37.2° S and 38.2° S.
4. Bay of Plenty. Catches from this area are included in QMA 1.
    a. North Colville. The area between 177.3° E and 177.7° E, and between 34.8° S and 35.2° S.
    b. Mercury-Colville. The area between 176.4° E and 177° E, and between 36° S and 36.7° S.
    c. White Island. The area between 177° E and 177.6° E, and between 36.75° S and 37.4° S.
5. North Challenger and Lord Howe. The area between 164° E and 169° E, and between 35° S and 38.5° S. This area is outside the New Zealand Exclusive Economic Zone (EEZ).

2.4 Standardised catch per unit effort (CPUE)

The data set used in this analysis differed from that used by Dunn (2007) and Field & Clark (2001), in two main respects.

1. The initial data set used all bottom tows considered to be capable of catching black cardinalfish, regardless of the reported target species. Because black cardinalfish fisheries focused on hills and other features (Dunn 2007), the 'cardinalfish capable tows' were first defined by their proximity to known underwater features, and then also by depth fished. Each of the data selection criteria was set such that the resulting data set included about 95% of the reported black cardinalfish target tows: 95% of the black cardinalfish target tows were within 16 n. mile of the nearest known feature, and a bottom depth range of 470–980 m (Figure 2).
2. In order to avoid the potential bias in catch reported identified by Dunn (2007), the data set was split in the period before, and including and after 1998–99. This splits the time series at the point when the black cardinalfish TACC was introduced. There were also other changes in fishing fleet composition and behaviour around this time, which supported splitting the data set at this time, and are described in Section 4.

Continuity rules were applied to the data selection to adequately estimate categorical predictor effects in the model. These specified that, to be included in the data set, there must have been at least 3 years with 10 or more non-zero catch tows per year for each *subarea* (being the specific nearest hill or feature), *vessel*, and *target species* (where applicable; the use of *target species* as a potential predictor is discussed in detail in section 4).

Similar to Field & Clark (2001) and Dunn (2007), the standardised CPUE analyses were carried out by fitting a generalised linear model to CPUE, using the stepwise multiple regression technique described by Francis (2001). The units of CPUE used were tonnes per tow (t/tow), and the dependent variable was log(t/tow). Since there was a non-trivial proportion of zero catch tows in the data set, the model for the CPUE was split into two parts, (1) a normal model for the natural log of the non-zero tows, with a normal error distribution and identity link function, and (2) a binomial model which estimates the probability of a non-zero catch, with a binomial response and logit link function. The combined model estimates catch rates from all tows (including those with zero catch) by combining results from the normal and binomial models. The coefficient of variation (c.v.) of the estimates from the combined model were calculated using a nested bootstrap procedure (Francis 2001).

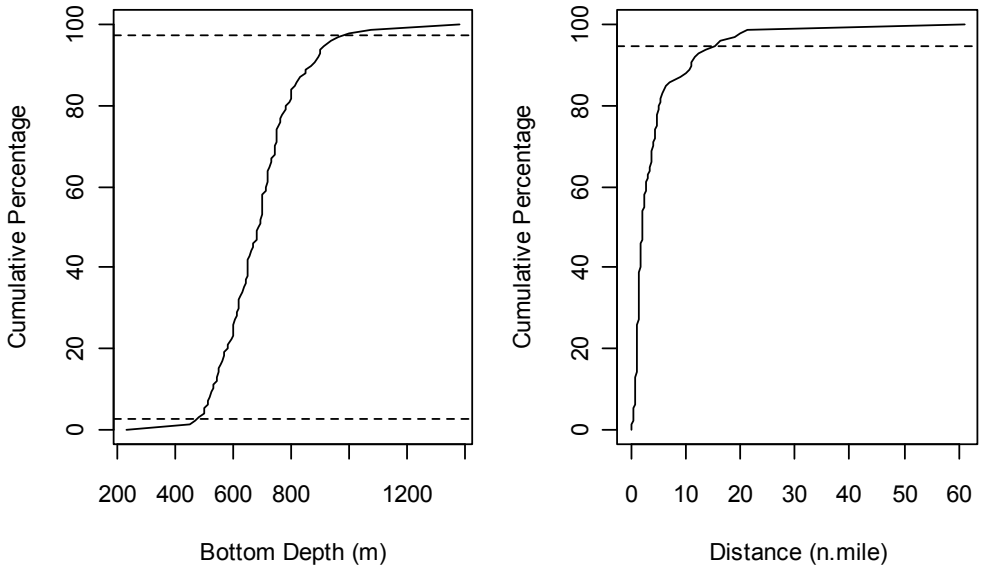

Figure 2: Cumulative frequency of black cardinalfish target tows by bottom depth (left panel) and distance from the nearest feature (right panel). The horizontal broken lines indicate for bottom depth the 2.5% and 97.5% quantiles, and for distance the 95% quantile.

The predictor variable *fishing year* was forced into the model, and other variables tested for inclusion (Table 1). A stepwise forward procedure was used to select predictor variables, and they were entered into the model in the order which gave the maximum decrease in the Akaike Information Criterion (AIC). Because it was considered possible that CPUE trends were different for each *subarea* and *target species*, interactions between these variables and *fishing year* were also tested for inclusion in the model. Other interactions were also tested, if the proposed effect seemed reasonable. Predictor variables were accepted into the final model if they explained at least 1% of the deviance and their predicted effects were sensible.

Table 1: Predictor variables used included in the standardised CPUE analysis.

Variable	Type	Comment	Variable	Type	Comment
Fishing year	Categorical	Forced into the model	Bottom depth	3rd order polynomial	–
Vessel	Categorical	Vessel key	Target species	Categorical	–
Subarea	Categorical	i.e., hill	Tow duration	3rd order polynomial	–
Distance from nearest hill	3rd order polynomial	Derived from positional data	Tow distance	3rd order polynomial	–
Month	Categorical	–	Length	3rd order polynomial	Vessel length
Fishing day	3rd order polynomial	Day of the fishing year	Tonnes	3rd order polynomial	Gross tonnage of vessel
Time	3rd order polynomial	Time of day tow was shot			

3. RESULTS

3.1 Overall fishery

Almost all catches have been made from trawls (Table 2). Except for 1991–92 and 1992–93, over 95% of the estimated catches were reported from bottom trawls.

Table 2: Estimated catches (t) of black cardinalfish by fishing method and by form type from 1990–91 to 2004–05.

	TCP		CEL and TCE				
Fishing year	Bottom trawl	Midwater trawl	Bottom trawl	Midwater trawl	Setnets	Lines	Other
1990–91	2 888.9	45.7	1 246.7	25.4	3.3	<1	0.1
1991–92	1 219.2	247.8	163.5	1.4	0.3	2.8	0
1992–93	1 865.0	145.9	148.3	0.8	<1	<1	0
1993–94	3 662.7	63.1	128.2	46.1	0.1	1.2	12.7
1994–95	3 214.3	73.3	225.4	0	<1	<1	0
1995–96	3 137.1	16.6	271.4	0	0	1	0
1996–97	3 757.0	52.5	287.2	0	0	<1	0
1997–98	2 295.3	58.5	61.0	2.5	0	<1	0
1998–99	2 201.4	56.4	67.8	<1	0	<1	3.6
1999–00	3 031.8	32.2	90.9	5.1	0	<1	0
2000–01	2 253.8	1.2	0	6.6	0	<1	0
2001–02	2 326.8	55.4	0.2	<1	0	<1	0
2002–03	2 671.9	57.1	4.8	<1	0	<1	2.2
2003–04	1 653.3	78.1	<1	<1	0	<1	0
2004–05	1 343.7	42.9	14.2	1.2	0	<1	0
2005–06	2 710.9	20.6	5.6	0	<1	1.0	0
2006–07	2 037.6	3.5	0.1	0	0	2.2	0
2007–08	980.9	42.2	<1	0	0	<1	0

For 1990–91 to 2004–05, the more detailed TCP and HTC data set described about 95% of the estimated catches, and the estimated catches about 92% of the reported catches (Table 3). Because the estimated catch data describe the majority of the catch in all years they should be representative of the fishery in the subsequent analyses.

Estimated catches of black cardinalfish have fluctuated, but overall have shown a slow decline. Dunn (2007) found the lowest catch since 1990–91 was in the last year studied, 2004–05. This was followed by two years of higher catches in 2005–06 and 2006–07, but the catch in the most recent year, 2007–08, was lower than in 2004–05 and now the lowest since 1990–91 (Table 4).

The largest fishery has continued to occur in CDL 2 (Table 7). The absolute values and trends in estimated catches were generally similar to the reported catches for the largest fisheries, which have been in QMAs 1, 2, & 3 (except for QMA 1 in 1998–99 and ET in 2007–08, Tables 8 & 9). The correspondence between estimated and reported catches was poorer and more variable for fisheries in other areas. In 2007–08, only 30.2% of the TACC was caught. The TACC for the largest fisheries in CDL1 and CDL 2 have never been restrictive (see Table 4). TACCs in CDL 4 and CDL 5 had occasionally been restrictive (especially for the former), and the TACC was increased from 1 October 2006.

Table 3: Estimated catch of black cardinalfish by form type (TCEPR or CELR), and the reported catch reproduced from the Fisheries Plenary Report (to the nearest t, MFish (2008)) for 1990–91 to 2007–08.

Fishing year	TCP & HTC	CEL, HCE & TCP	Proportion TCP & HTC	Reported catch	Estimated as proportion of reported catch
1990–91	2 934.6	1 276.3	0.70	4 311	0.98
1991–92	1 467.0	168.1	0.90	1 838	0.89
1992–93	2 010.8	149.9	0.93	2 366	0.91
1993–94	3 725.8	188.2	0.95	3 801	1.03
1994–95	3 287.6	226.1	0.94	3 710	0.95
1995–96	3 169.7	272.5	0.92	4 490	0.77
1996–97	4 048.1	287.2	0.93	4 567	0.95
1997–98	2 354.1	63.7	0.97	2 743	0.88
1998–99	2 257.9	71.9	0.97	1 921	1.21
1999–00	3 064.0	96.4	0.97	4 377	0.72
2000–01	2 254.9	6.9	1.00	2 213	1.02
2001–02	2 382.1	1.8	1.00	2 839	0.84
2002–03	2 729.0	8.2	1.00	2 996	0.91
2003–04	1 731.4	0.2	1.00	1 785	0.97
2004–05	1 386.6	16.0	0.99	1 683	0.83
2005–06	2 731.6	6.6	1.00	2 945	0.93
2006–07	2 041.1	2.3	1.00	2 218	0.92
2007–08	1 023.1	0.1	1.00	1 134	0.90

Table 4: Reported catches (to the nearest tonne) of black cardinalfish by QMA (MFish Science Group 2008). The Total Allowable Commercial Catch (TACC) is shown in the last row.

Fishing year	1	2	3	4	5	6	7	8	9	ET	Total
1990–91	233	3 473	589	1	4	0.5	1	0.5	0	0	4 302
1991–92	7	1 652	146	3	0.5	0	11	0	0	17	1 837
1992–93	23	1 550	519	2	0.5	0	2	0	0	270	2 367
1993–94	364	2 310	277	10	5	0	6	0	0	829	3 801
1994–95	1 162	2 207	51	7	1	0	51	0	0.5	231	3 711
1995–96	1 418	2 621	57	4	10	0	26	0	0	340	4 476
1996–97	2 001	1 910	100	7	0	0	27	0	0	522	4 567
1997–98	995	1 176	40	351	0	0	76	0	108	405	3 151
1998–99	24	1 268	181	41	0	0.5	16	0.5	0.5	390	1 922
1999–00	980	2 158	215	36	0.5	0	27	0	0.5	962	4 379
2000–01	294	1 135	99	35	74	0	2	0	3	571	2 213
2001–02	455	1 693	146	29	18	0	3	0	5	490	2 839
2002–03	583	1 845	172	80	9	0	27	0	5	275	2 996
2003–04	481	966	96	148	27	0	2	0	6	58	1 784
2004–05	267	1 102	43	49	15	0.5	2	0	1	204	1 684
2005–06	643	2 153	50	53	0.5	0.5	0.5	0	2	44	2 767
2006–07	415	1 692	66	31	10	0.5	1	0	1	2	2 219
2007–08	202	861	7	23	20	0	2	0	19	1	1 135
TACC	1 200	2 223	196	66	22	1	39	0	4	–	3 760

Table 5: Estimated catches (to the nearest tonne) of black cardinalfish by QMA. The Total Allowable Commercial Catch (TACC) is shown in the last row, and came into effect on 1 October 1998 (the 1998–99 fishing year).

Fishing year	1	2	3	4	5	6	7	8	9	ET	Total
1990–91	87	2 944	1 074	5	2	<1	<1	0	0	<1	4 211
1991–92	2	1 244	348	15	1	0	15	0	0	10	1 635
1992–93	1	1 386	437	1	0	0	1	<1	0	184	2 161
1993–94	100	2 399	194	3	3	0	37	0	0	1 064	3 914
1994–95	1 079	1 913	243	1	0	0	<1	6	0	225	3 514
1995–96	1 311	1 553	179	4	8	0	1	0	<1	275	3 442
1996–97	1 872	1 637	308	8	0	0	7	0	0	470	4 335
1997–98	1 088	1 027	101	13	0	1	0	0	1	187	2 418
1998–99	624	1 078	208	32	0	0	20	0	<1	360	2 330
1999–00	863	1 845	245	19	0	<1	13	0	<1	163	3 160
2000–01	216	1 063	94	28	58	0	<1	0	1	503	2 262
2001–02	374	1 600	137	13	13	0	1	0	1	162	2 384
2002–03	530	1 712	171	64	2	0	<1	0	3	251	2 737
2003–04	454	947	90	106	21	0	<1	0	2	91	1 732
2004–05	199	929	41	34	12	1	2	0	<1	185	1 403
2005–06	518	2 086	48	47	<1	0	<1	0	<1	34	2 738
2006–07	384	1 562	56	25	14	0	<1	0	<1	2	2 043
2007–08	159	758	5	14	19	<1	0	0	<1	16	1 023
TACC	1 200	2 223	196	66	22	1	39	0	4	–	3 760

Table 6: Estimated catches (Table 4) as a proportion of the reported catches by QMA (MFish 2008). MFish (2008) give no catches for QMA 10. "NA" indicates estimated catches but no reported catches.

Fishing year	1	2	3	4	5	6	7	8	9	ET
1990–91	0.37	0.85	1.82	4.7	0.53	0	0	–	–	NA
1991–92	0.29	0.75	2.38	4.87	1.4	–	1.37	–	–	0.61
1992–93	0.05	0.89	0.84	0.3	–	–	0.6	NA	–	0.68
1993–94	0.27	1.04	0.7	0.34	0.56	–	6.18	–	–	1.28
1994–95	0.93	0.87	4.76	0.17	–	–	0	NA	–	0.97
1995–96	0.92	0.59	3.13	1.1	0.84	–	0.02	–	NA	0.81
1996–97	0.94	0.86	3.08	1.1	–	–	0.27	–	–	0.9
1997–98	1.09	0.87	2.52	0.04	–	NA	–	–	0.01	0.46
1998–99	26.02	0.85	1.15	0.79	–	–	1.23	–	0.2	0.92
1999–00	0.88	0.85	1.14	0.53	–	–	0.5	–	0	0.17
2000–01	0.73	0.94	0.95	0.81	0.78	–	0	–	0.23	0.88
2001–02	0.82	0.95	0.94	0.46	0.69	–	0.17	–	0.14	0.33
2002-03	0.91	0.93	0.99	0.8	0.18	–	0.01	–	0.6	0.91
2003-04	0.94	0.98	0.94	0.72	0.78	–	0.05	–	0.37	1.57
2004-05	0.75	0.84	0.95	0.69	0.81	1.4	0.8	–	0.3	0.91
2005–06	1.12	0.97	0.96	0.88	0	–	0	–	0	0.78
2006–07	0.92	0.92	0.85	0.81	1.4	–	0.4	–	0.3	1.2
2007–08	0.79	0.88	0.76	0.61	0.93	–	–	–	0.01	16.3

The areas fished in the last two years are similar to those fished in previous years, with no large and new fisheries having developed (Figure 3) (Dunn 2005, 2007).

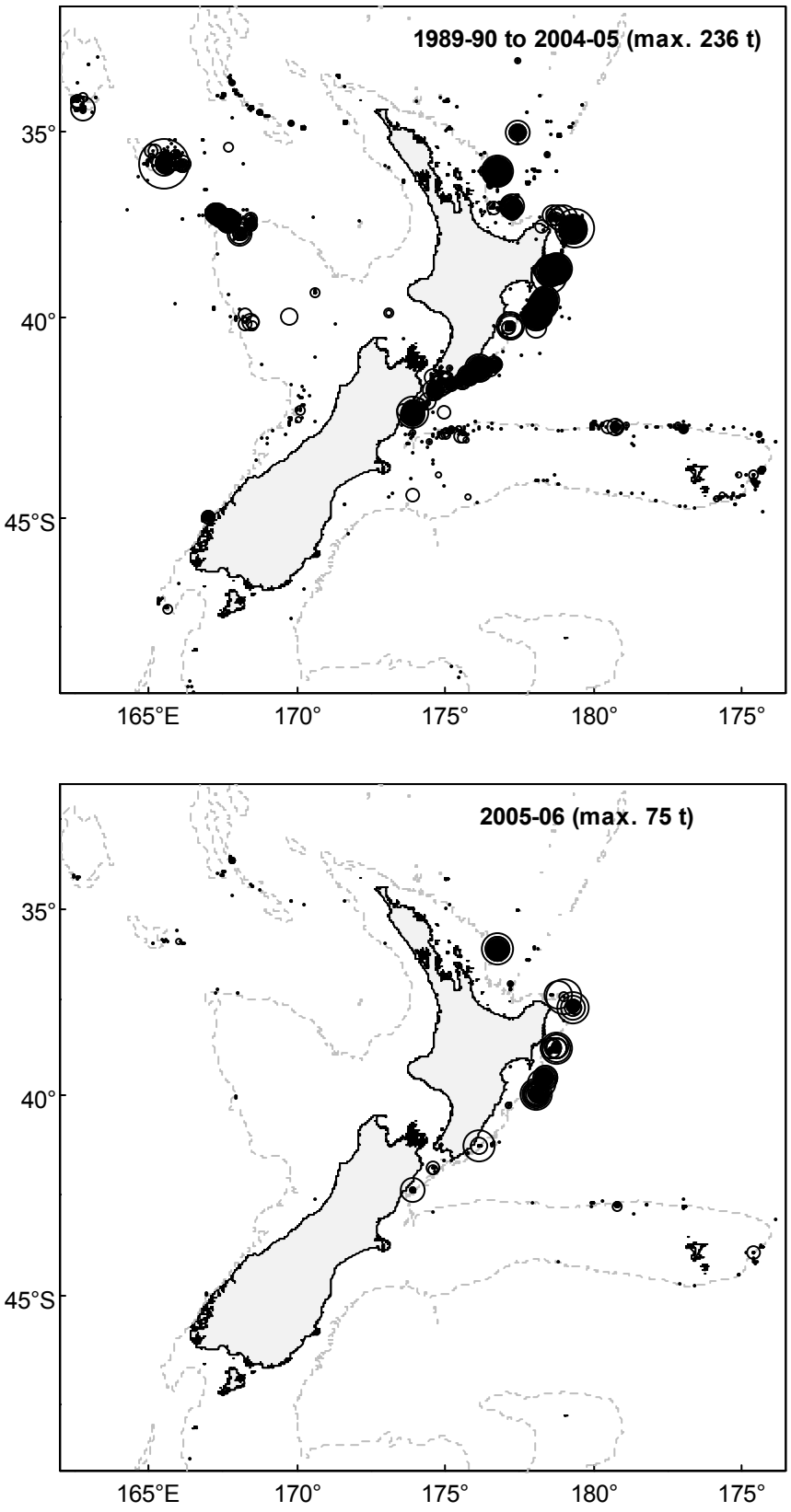

Figure 3: Unstandardised estimated catch rates (t/tow) of black cardinalfish by fishing year, for tows from all trawls by fishing year, with circle area proportional to catch rate (maximum shown in parentheses), with the 1000 m isobath shown by the broken line.

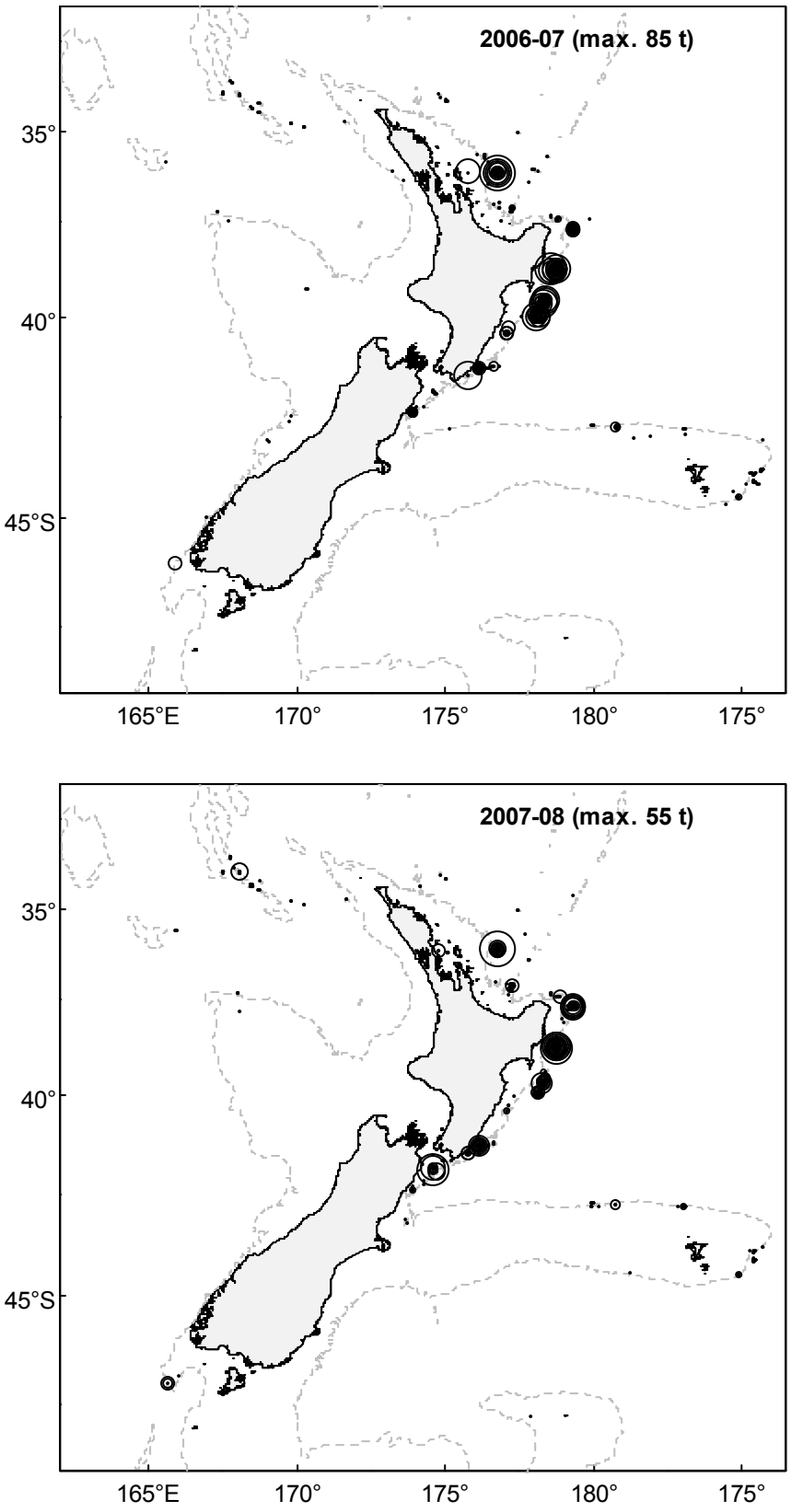

Figure 3 (cont.): Unstandardised estimated catch rates (t/tow) of black cardinalfish by fishing year, for tows from all trawls by fishing year, with circle area proportional to catch rate (maximum shown in parentheses), with the 1000 m isobath shown by the broken line.

Over the last three years, the fisheries just outside the EEZ on the North Challenger Plateau were almost absent, and the incidence of large catches in the fisheries off Kaikoura and Wairarapa, and in the Bay of Plenty, was reduced (Figure 3).

Estimated catches in the Kaikoura region were relatively low from 2004–05 to 2006–07, increasing in 2007–08 (Table 7). Catches from Wairarapa were relatively low in recent years. The catches from the East Coast and Bay of Plenty, historically the largest fisheries, both reached their lowest level in 2007–08 since the development of the fisheries. The fishery on North Challenger and Lord Howe effectively ceased from 2005–06. The areas defined by Dunn (2005) include 84.5% of the total estimated catch from 1990–91 to 2007–08, and 93% of the estimated catch over the last three fishing years.

Table 7: Estimated catches (t) of black cardinalfish by fishery area (t) and fishing year. Catches from "Other EEZ" are largely from the west coast South Island and the Chatham Rise.

Fishing year	Kaikoura	Wairarapa	East Coast	Bay of Plenty	Other EEZ	North Challenger and Lord Howe	Other ET
1990–91	522	114	2 905	87	583	NA	<1
1991–92	180	208	1 034	2	200	10	0
1992–93	464	245	1 111	1	155	175	10
1993–94	162	384	2 012	100	193	1062	1
1994–95	118	270	1 576	1 079	245	207	18
1995–96	21	82	1 533	1 310	220	245	30
1996–97	72	347	1 263	1 872	312	451	19
1997–98	39	29	989	1 088	85	162	25
1998–99	155	127	934	624	130	316	44
1999–00	207	161	1 664	863	103	152	11
2000–01	84	196	865	216	397	485	18
2001–02	168	163	1 400	374	116	159	3
2002–03	182	266	1 430	530	78	224	27
2003–04	129	167	730	454	161	42	49
2004–05	51	123	791	199	53	118	67
2005–06	64	91	1 980	518	51	7	27
2006–07	57	155	1 405	384	40	<1	2
2007–08	118	93	603	159	33	<1	16

Most black cardinalfish catches have been from tows where black cardinalfish was the reported target species (Table 8). The proportion of black cardinalfish catches from target tows has been increasing, and since 2001–02 more than three–quarters of the catch has come from target tows, peaking at 94% in 2006–07. The black cardinalfish taken as bycatch have been most frequent in the orange roughy target tows, except for 2007–08, where the largest bycatch was from hoki target tows (Table 8).

The overall statistics are summarised for the two largest fisheries, in CDL 1 and CDL 2, in Figures 4 and 5. The number of vessels catching black cardinalfish in the CDL 1 fishery decreased slowly from 11 to 17 during 1990–91 to 1996–97, to 6 in 2007–08 (Figure 4). The number of vessels targeting black cardinalfish was less variable, with 3 or 4 vessels targeting since 2003–04. The estimated catch decreased from a peak in 1996–97 to a low (since the fishery developed) in 2007–08. The median unstandardised catch rate (t/tow) of the target fishery was variable, but remained relatively low at 100 kg/tow since 2004–05. The proportion of successful tows has remained much the same, at about 0.5. The number of tows targeting black cardinalfish has decreased, but the proportion of the catch taken in targeted tows has increased, reaching 0.99 in 2000–01, 2003–04, and 2006–07. The median targeted

tow duration has been short, except for 1990–91, which is likely to be unusual or a mistake. The median targeted tow duration was 0.33–1.08 hours between 1993–94 and 2000–01, and then shortened to 0.12–0.18 hours in 2001–02 to 2007–08, being 0.12–0.13 hours for the last 3 years. The number of hills targeted (defined as a tow within 5 n.mile of the feature summit) increased from 2 to a peak of 10 in 2003–04 to 2005–06, and subsequently decreased to 6 in 2007–08. These statistics suggest there is now a small fleet targeting black cardinalfish in CDL 1, moving towards greater targeting of black cardinalfish using short tows over a relatively small area, and although fishing success (i.e., catch or not) has remained unchanged, there has been a decline in catch, effort, and catch rate. Only 16.8% of the CDL 1 TACC was caught in 2007–08.

Table 8: Estimated catch of black cardinalfish by target species and fishing year, and the percentage of estimated black cardinalfish catch taken in the target fishery.

Fishing year	Bluenose	Alfonsino	Black cardinalfish	Hoki	Orange roughy	Oreos	Other	% Target
1990–91	10.9	41.0	2 797.2	300.2	983.3	72.9	5.3	0.66
1991–92	3.3	246.8	750.0	67.0	567.2	0.5	0.3	0.46
1992–93	0.8	221.7	767.5	227.5	853.2	87.0	3.1	0.36
1993–94	0.6	175.8	1 328.9	92.9	2 264.3	48.6	2.9	0.34
1994–95	3.4	273.5	2 132.9	3.0	1 094.9	2.5	3.5	0.61
1995–96	0.2	114.8	2 047.2	40.0	1 191.0	48.1	0.7	0.59
1996–97	25.3	138.5	2 234.9	176.6	1 673.8	66.1	20.1	0.52
1997–98	3.0	45.7	1 442.4	52.8	854.5	19.4	0	0.60
1998–99	0.1	48.2	1 382.1	197.0	696.4	0	5.9	0.59
1999–00	31.5	18.7	2 162.8	271.6	674.1	0.5	1.1	0.68
2000–01	14.2	48.6	1 430.7	221.5	545.8	0.9	0.2	0.63
2001–02	0.9	23.0	1 950.1	163.1	246.6	0	0.2	0.82
2002-03	2.2	70.7	2 233.0	276.6	154.2	0.1	0.5	0.82
2003-04	18.9	106.5	1 318.3	152.9	134.8	0.1	0	0.76
2004-05	6.0	25.6	1 140.2	90.3	137.8	1.0	1.7	0.81
2005–06	1.1	35.7	2 450.2	97.8	153.2	0	0.2	0.89
2006–07	2.2	55.3	1 913.8	31.1	26.7	0	14.3	0.94
2007–08	0.1	32.3	762.6	138.6	70.4	0	19.0	0.75

The number of vessels catching black cardinalfish in the CDL 2 fishery decreased from 26 to 32 between 1990–93 and 1995–96, to 11 in 2007–08 (Figure 5). The number of vessels targeting was lower but similarly declined, from 12 vessels in 2004–05 to 5 in 2007–08. The estimated catch was variable but with no clear trend, although there were peaks in catch roughly every 3 years. The median unstandardised catch rate (t/tow) declined rapidly between 1990–91 and 1995–96, and then remained relatively low or decreased slightly, at 0.5 t/tow or less since 2001–02, and 0.1 t/tow in 2007–08. The proportion of successful tows has remained much the same, at about 0.5. The number of tows targeting black cardinalfish increased, peaking in 2006–07, and the proportion of the catch taken in targeted tows increased, to at least 0.8 since 2000–01. The median targeted tow duration was short, at 0.5–1.0 hour before 2001–02 and about 0.4 hours from 2001–02 to 2007–08. The number of hills targeted (defined as a tow within 5 n.mile of the feature summit) increased to a peak of 19 in 1999–2000, and then reduced to 12–16 between 2000–01 and 2007–08. These statistics suggest the fleet catching and targeting black cardinalfish in CDL 2 has been decreasing, but with an increase in effort (tows) and targeting of black cardinalfish using shorter tows over a relatively stable area, for the same catch levels, and although fishing success (catch or not) has remained unchanged, there has been a decline in catch rate. Only 38.7% of the CDL 2 TACC was caught in 2007–08.

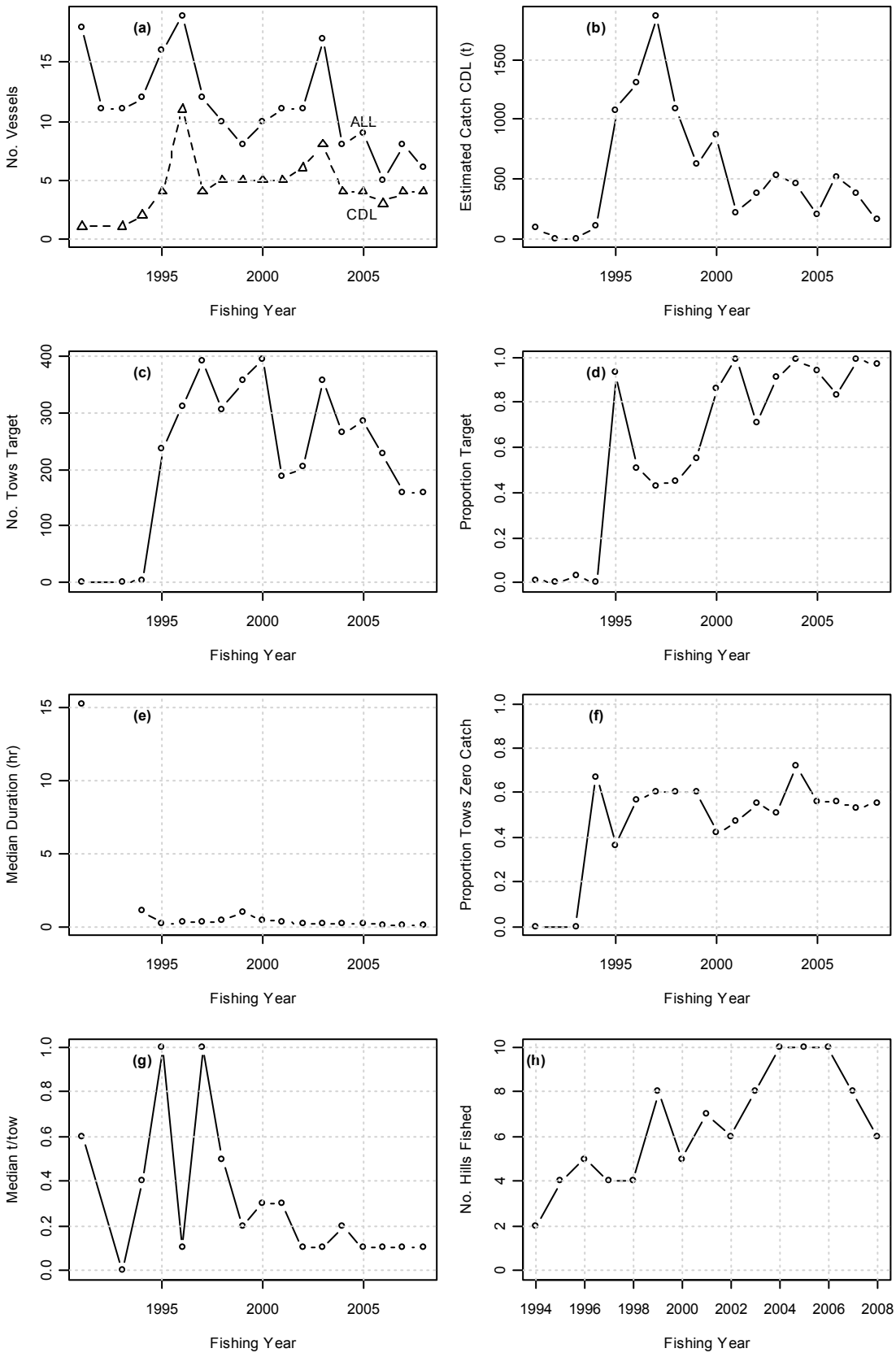

Figure 4: Summary statistics for the CDL 1 fishery: (a) number of all (ALL) and targeting (CDL) vessel; (b) estimated catch; (c) number of targeted tows; (d) proportion of black cardinalfish caught in targeted tows; (e) median targeted tow duration; (f) proportion of non-zero catch targeted tows; (g) median targeted t/tow; (h) number of hills where black cardinalfish targeted.

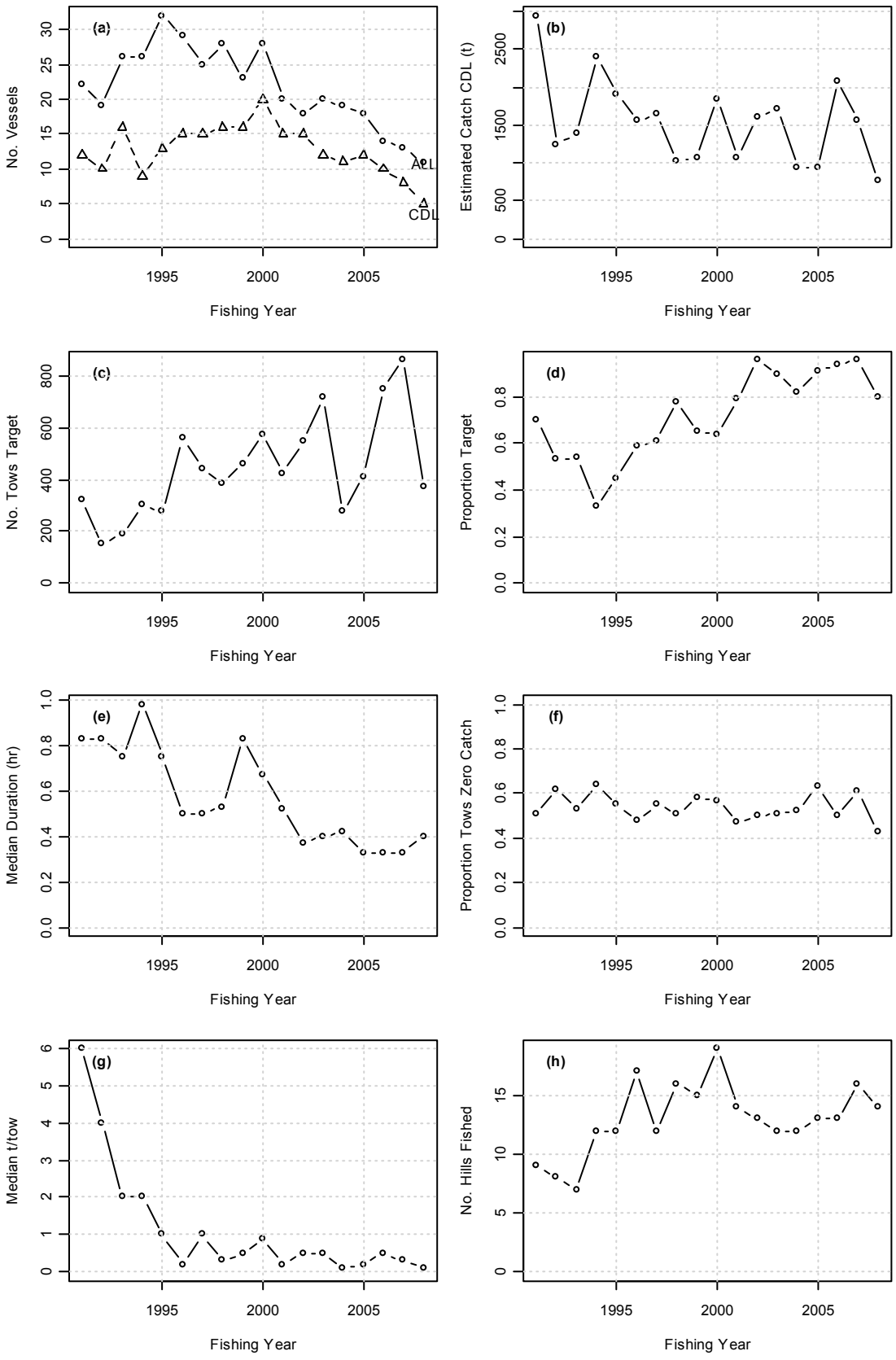

Figure 5: Summary statistics for the CDL 2 fishery: (a) number of all (ALL) and targeting (CDL) vessel; (b) estimated catch; (c) number of targeted tows; (d) proportion of black cardinalfish caught in targeted tows; (e) median targeted tow duration; (f) proportion of non-zero catch targeted tows; (g) median targeted t/tow; (h) number of hills where black cardinalfish targeted.

3.2 Kaikoura

The fishing locations in Kaikoura have remained the same, with two main fishing areas persisting (Figure 6). The southern area has been focused on the Kaikoura hill, and fished at depths of about 700 m (Figure 6). The more northern area is in the approaches to Cook Strait, and fished shallower, at around 400 m. The cardinalfish catches alternated between these locations in 2006–07 and 2007–08.

The Kaikoura fishery has continued to be a relatively small and almost entirely bycatch fishery for black cardinalfish. Fewer than 20 tows a year have reported targeting black cardinalfish (Figure 6). Since 2004–05 the number of tows catching black cardinalfish as a bycatch was relatively low (13–25), and the number of target tows relatively high (8–14). The target species in this fishery has been predominantly hoki (Dunn 2007). The unstandardised catch rates have been erratic, especially in the target fishery. In the bycatch fishery, catch rates decreased after a peak in 2002–03, but then increased substantially in 2007–08. The black cardinalfish estimated catch in 2007–08 was also relatively high (118 t), following 3 years of relatively low catch (26–49 t).

Most of the catch was taken in December and January in 2005–06, and December and May in 2007–08 (Figure 6). In 2006–07 the catch uptake was more even, with relatively large catches in November, February, April, and May. The catch uptake was relatively slow through the year in 2007–08, with only 1997–98 being slower. This seasonality is consistent with previous years (Figure 6, Dunn 2007).

3.3 Wairarapa

The fishing locations in Wairarapa have remained much the same, with the focus of past and recent catches being a feature south of the Castlepoint Hills, at a depth of around 600 m (Figure 7). This feature has a surface depth of 500 m, and an elevation of just over 500 m (Dunn 2007). Catches on the Castlepoint Hills themselves have always been relatively small, but larger catches have been taken in some years in the south of the Wairarapa region. The catches declined (Dunn 2005), and have remained low.

The Wairarapa fishery has been substantial in some years (about 380 tonnes estimated catch in 1993–94), but catches have declined, with most taken in tows targeting black cardinalfish (Figure 7). Over the last 3 years the catches from the target fishery have been slightly larger (mean of 64 t) than the bycatch in other fisheries (mean of 49 t). The catches from the target fishery peaked in 2002–03, at about 229 t. The total estimated catch reached an historical low in 2005–06, at about 90 t.

Since 1990–61 the fishery has predominantly been a target fishery: more than twice as many tows were reported as targeting black cardinalfish than caught black cardinalfish as a bycatch (Figure 7). In earlier years, black cardinalfish were largely a bycatch in the alfonsino target fishery (Dunn 2005). Targeted effort has been variable, and shown no clear trend. Despite the predominance of reported targeted tows, the unstandardised catch rates have often been substantially higher in the bycatch fishery, where the catch rate exceeded 3.9 t/tow in 8 years, peaking at 5.7 t/tow, whereas the catch rate from the target tows never exceeded 3.1 t/tow. The catch rates do not indicate any clear trend, but the catch rate in the bycatch fishery has peaked every 3 or 4 years. Large catches have been taken throughout the year, especially during December, January, March, and September in 2006–07 and 2007–08 (Figure 7). This pattern is typical of previous years (Figure 7, Dunn 2007). In 2005–06 an unusually large catch of 70 t was taken in October.

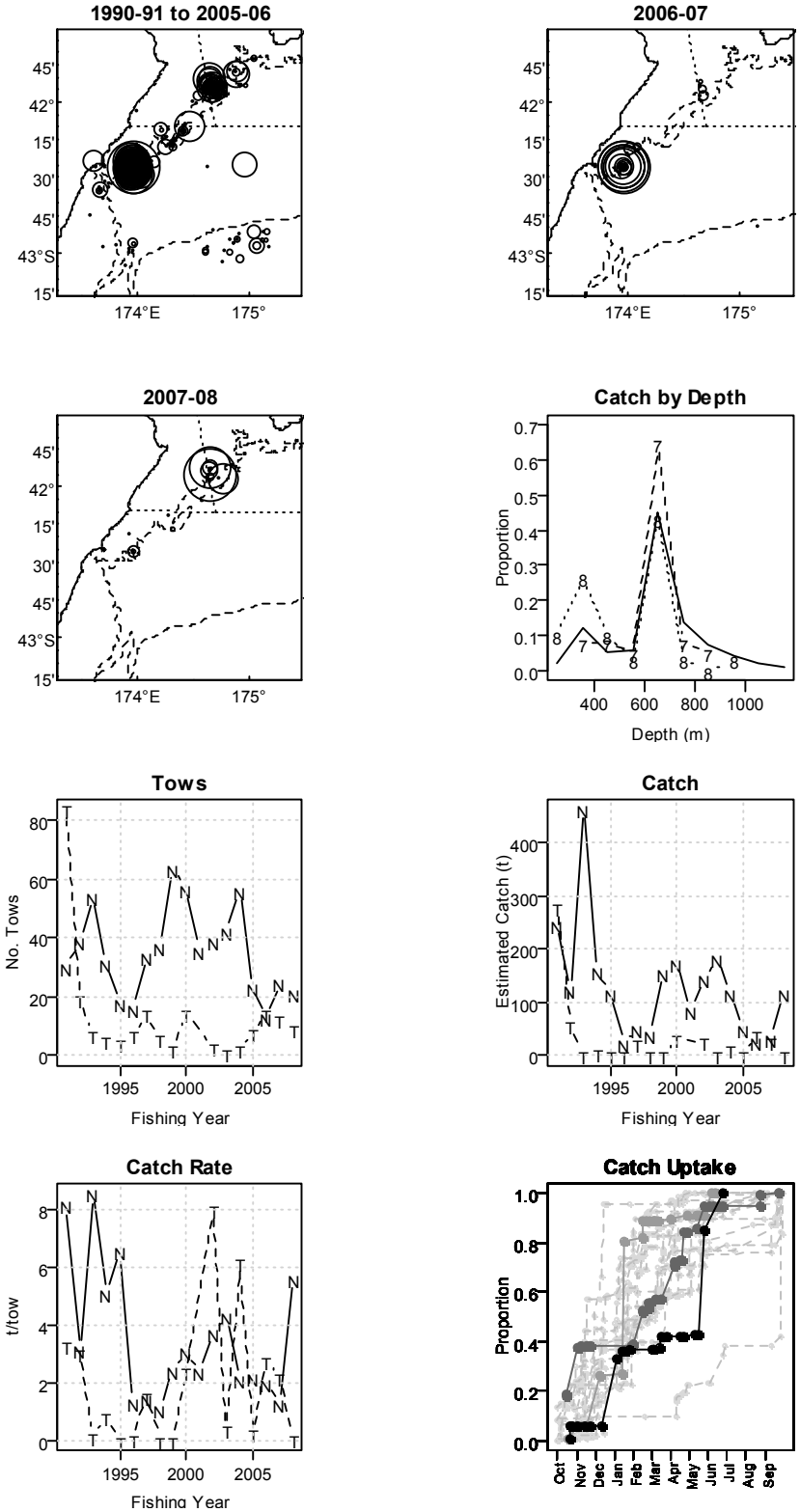

Figure 6: Statistics for the Kaikoura black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 85 t, 11t and 50t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T")0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

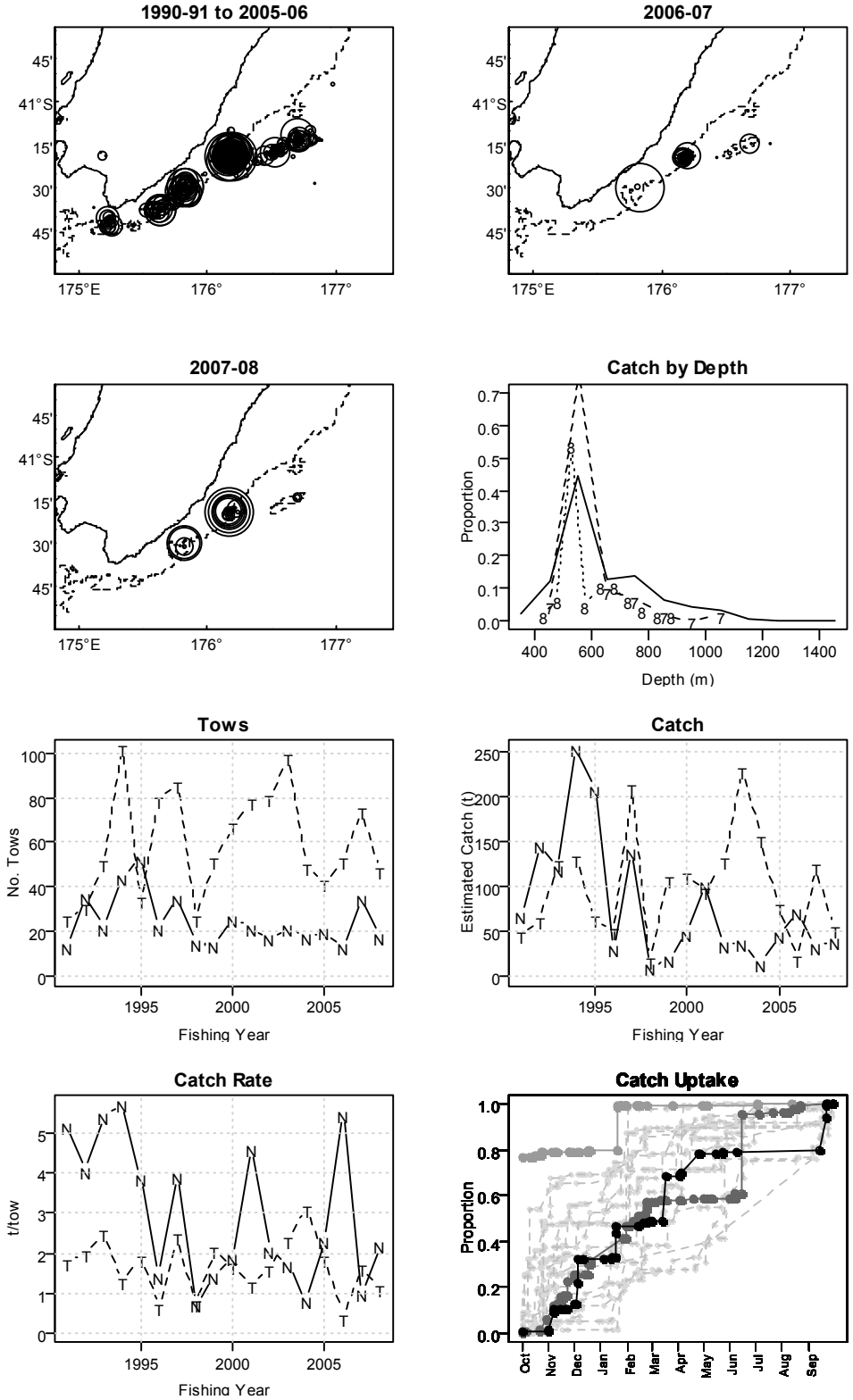

Figure 7: Statistics for the Wairarapa black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 70 t, 55 t and 18 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T")0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

3.4 East Coast

The East Coast fishery has historically been the largest, and was split into three areas by Dunn (2005, 2007). These were, from north to south, East Cape, Tuaheni, and Ritchie and Rockgarden.

The fishing locations have remained similar to those described by Dunn (2005, 2007). The East Cape fishery has remained focused on the East Cape hills, at a depth of about 700 m. The area to the northwest of the East Cape hills has only been fished intermittently (Figure 8). The Tuaheni fishery has become increasingly focused on the Tuaheni Hill itself, at a depth of about 750 m (Figure 9). The Ritchie and Rockgarden fishery has continued to operate over both areas, at depths between 600 and 800 m (Figure 10).

Of the three areas, the greatest effort and catches of black cardinalfish have been at Tuaheni and Ritchie and Rockgarden, with East Cape smaller but still about twice the size of the Wairarapa fishery. At East Cape most effort and catch since 1992–93 has targeted black cardinalfish, with targeted effort increasing after a low in 2001–02, and exceeding 100 tows per year in the last 3 years. Catch from the targeted tows reached a low of just 6 t in 2000–01, and then increased to 370 t in 2005–06, and was 165 t in 2007–08.

The fishery at Tuaheni caught over 1700 t in 1990–91, but subsequent catches have been substantially lower (see Figure 9). The targeted catch increased after a low of 8 t in 1997–98 to 777 t in 2002–03, and then declined, to 297 t in 2007–08. The target effort remained relatively high since 1998–99 and has exceeded 100 tows per year, peaking at 301 tows in 2006–07. Since 2001–02, the bycatch of black cardinalfish at Tuaheni has been negligible (less than 30 t per year).

The black cardinalfish catch at Ritchie and Rockgarden was largely bycatch before 1995–96, but the targeted fishery has developed and since 1997–98 almost all tows catching black cardinalfish have been targeted, and effort and catch have increased, peaking at 463 tows and 1181 t in 2005–06 (Figure 10).

Unstandardised catch rates in all three areas have been variable, although the highest catch rates occurred in the early 1990s. Bycatch catch rates at Ritchie and Rockgarden were at an historical low of 0.4 t/tow in 2007–08, down from 5.5 t/tow in 1992–93 (a decline of over 90%, Figure 10). The target catch rates at Ritchie and Rockgarden did not decline as much, and were 0.8 t/tow in 2004–05 and 2007–08, down from 3 t/tow in 1992–93, 1997–98 and 2001–02. Target catch rates at Tuaheni reached an historical low of 0.2 t/tow in 1997–98, down from 8.5 t/tow in 1991–92, but have then been higher and shown little trend, with a catch rate of 2.8 t/tow in 2007–08 (see Figure 9). At East Cape, target catch rates decreased from 2.5 t/tow in 1994–95 to 0.2 t/tow in 2000–01, but then increased to a high of 3.4 t/tow in 2005–06, and were 1.5 t/tow in 2007–08 (see Figure 8).

At East Cape the uptake of the catch through the year has been relatively steady, with relatively high catches between November and April (see Figure 8). At Tuaheni the fishery was relatively late to start during the last 3 years, with catch taken between January and early July, with the last catches taken during August (see Figure 9). At Ritchie and Rockgarden the catch was greatest between November and May, with a drop in effort and catch in July and August, but with good catches early in the season in 2006–07 and about one quarter of the annual catch taken in September in 2005–06 and 2007–08 (Figure 10).

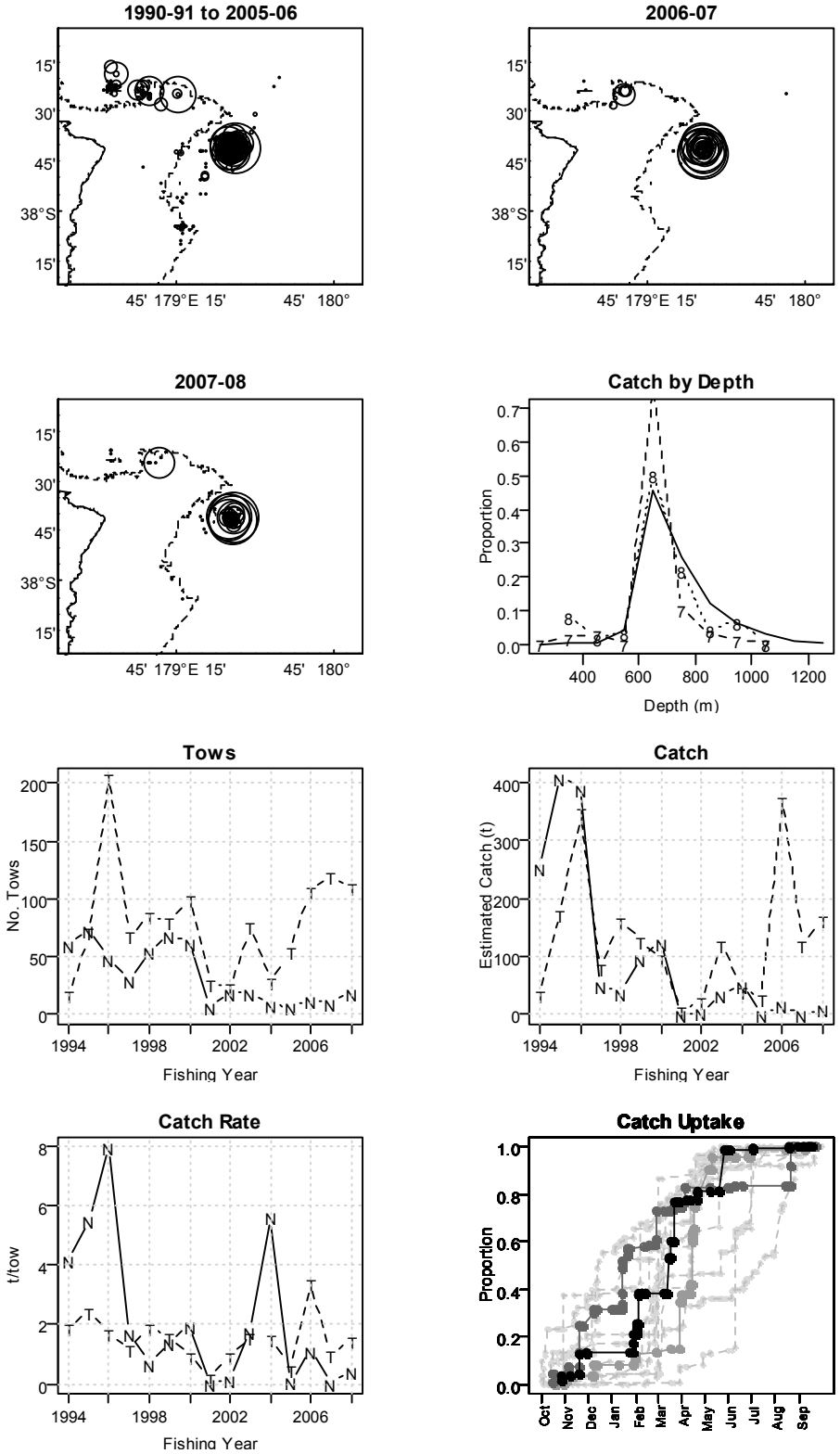

Figure 8: Statistics for the East Cape black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 147 t, 15 t and 30 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T")0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

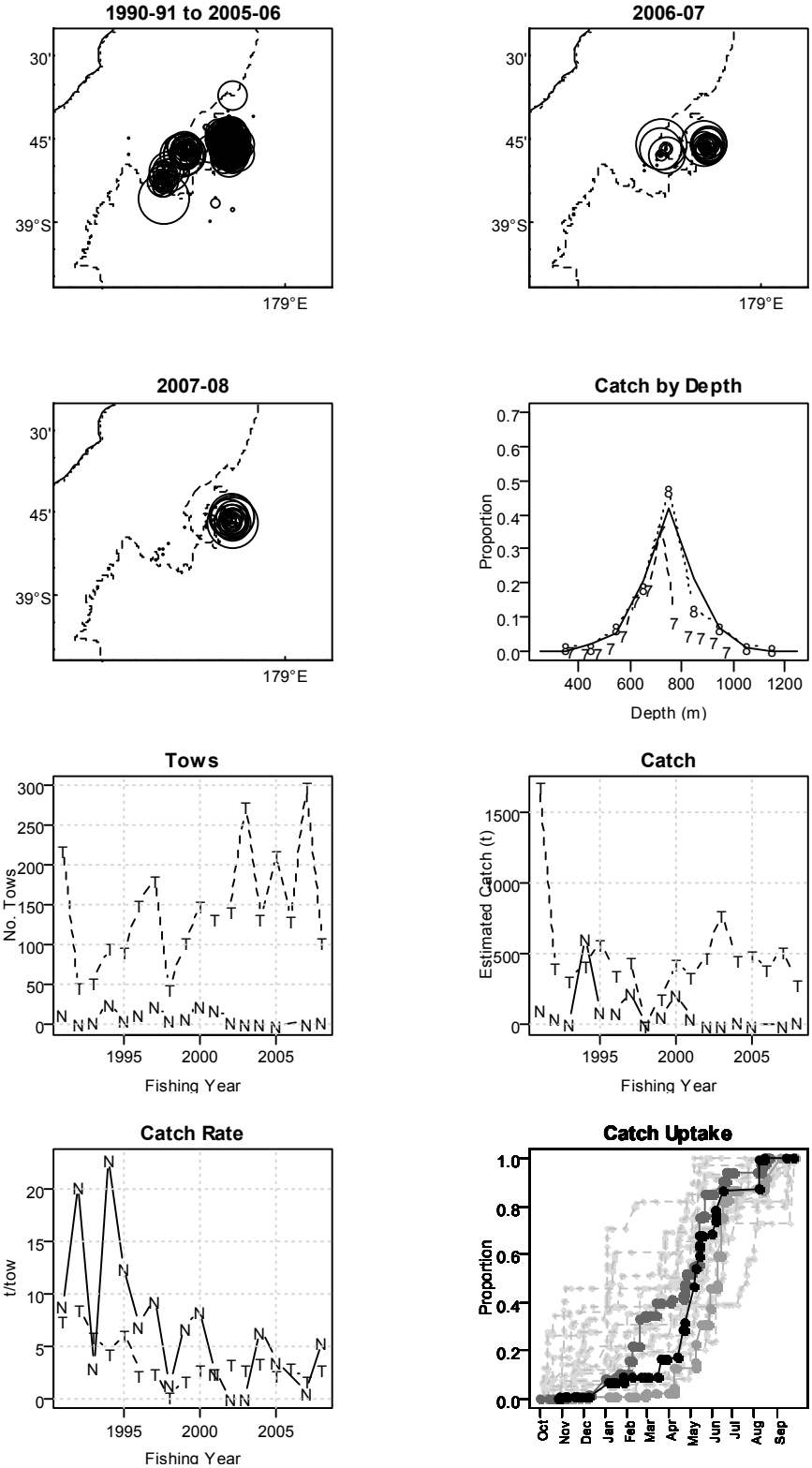

Figure 9: Statistics for the Tuaheni black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 77 t, 61 t and 19 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T")0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

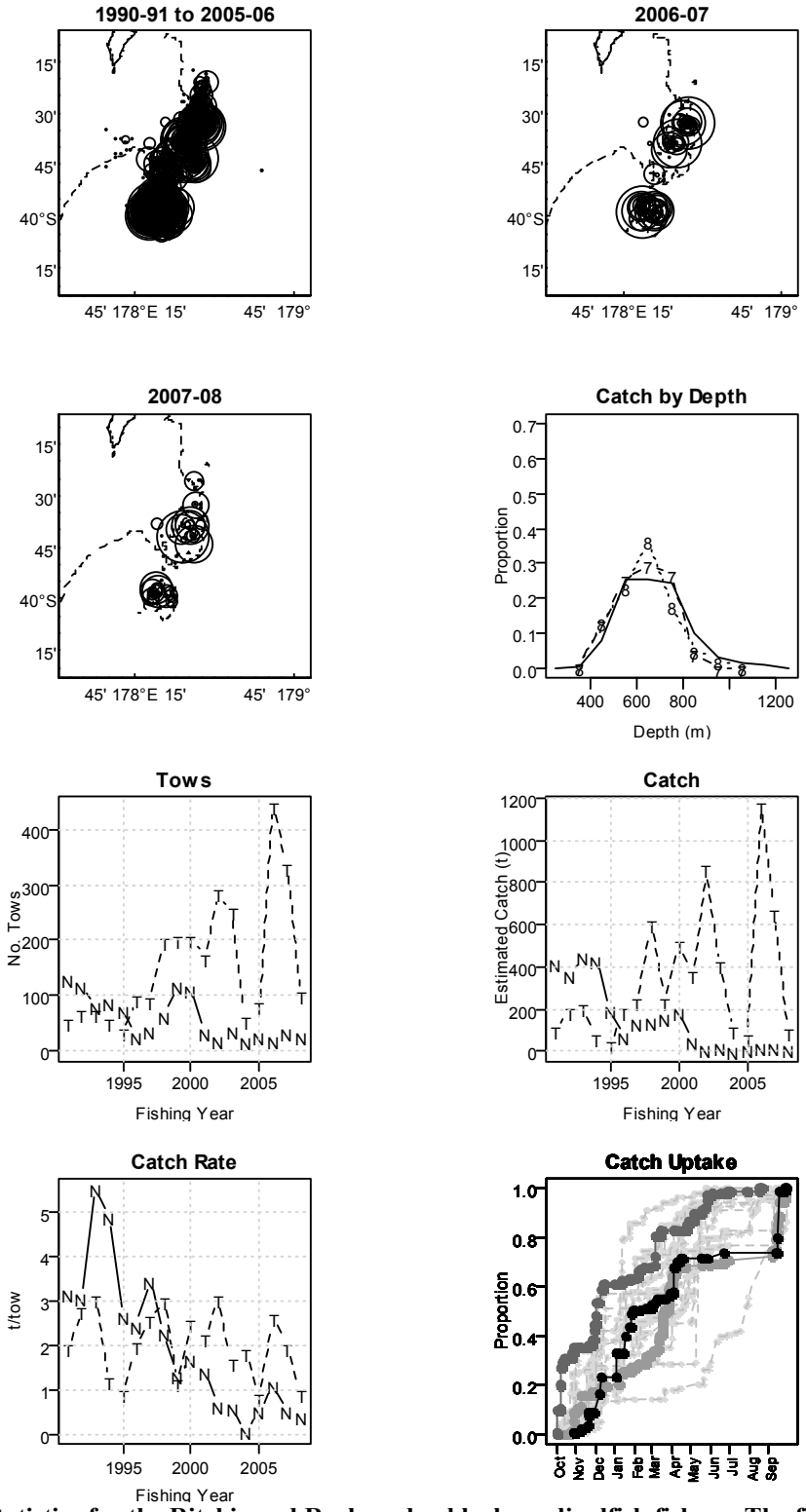

Figure 10: Statistics for the Ritchie and Rockgarden black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 120 t, 70 t and 49 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T"0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

3.5 Bay of Plenty

The Bay of Plenty fisheries were the most recent to develop. Dunn (2005, 2007) described three distinct areas: Mercury-Colville, North Colville, and White Island. The fishing locations in all three areas have remained the same, and focused on specific features (Figures 11–13), although catches at White Island were relatively shallow in 2006–07 and 2007–08 (Figure 13).

Of the three areas, the greatest catches of black cardinalfish have been at Mercury-Colville (Dunn 2005, 2007). Mercury-Colville has been largely a target fishery, and targeted catch and effort reached a low of 124 t and 99 tows in 2007–08, down from 1000 t in 1994–95 and 372 tows in 1996–97 (Figure 11). In North Colville, black cardinalfish was essentially targeted between 1999–2000 and 2005–06, with targeted tows and catch peaking in 2002–03 at 128 tows and 191 t, but then declining to just one tow and 1.2 t in 2006–07, and 2 tows and 0.5 t in 2007–08 (Figure 12). At White Island, most black cardinalfish have been caught in targeted tows, which peaked in 1998–99 with 205 tows and 187 t, and then declined to just 9 tows and 4 t in 2005–06, recovering slightly to 40 tows and 21 t in 2007–08 (Figure 13).

Unstandardised catch rates in all 3 areas have been variable. The highest catch rate recorded was as a bycatch in the Mercury-Colville fishery, at 14 t/tow in 2001–02 (Figure 11). The catch rate in the target fishery at Mercury-Colville dropped from 4.3 t/tow in 1994–95 to 0.9 t/tow in 2004–05, recovering to 1.3 t/tow in 2007–08. At North Colville the catch rates in the target fishery were 1.7 t in 1999–2000, reducing to 1.5 t in 2005–06 (Figure 12). At White Island the catch rates were never high, and for target tows peaked at 0.9 t/tow in 1997–97, reducing to 0.1 t/tow in 2004–05, and were 0.5 t/tow in 2007–08 (Figure 13).

At Mercury-Colville the uptake of catch through the year has become erratic, with catches through the year in 2005–06, but catches largely in August in 2006–07, and November in 2007–08 (Figure 11). Catches at North Colville have continued to be sporadic (Figure 12). At White Island the catch in 2005–06 was taken largely between February and September, but in 2006–07 and 2007–08 the catch was taken unusually early, in December and November respectively.

Deepwater trawling in the Bay of Plenty is influenced by the Adaptive Management Programme in place for orange roughy since 2000–01 (MFish Science Group 2008). However, it is unknown to what extent this may have influenced fishing for black cardinalfish.

3.6 North Challenger and Lord Howe

The North Challenger and Lord Howe fishery is just outside the New Zealand EEZ, where black cardinalfish have been caught in targeted tows since the early 1990s (Dunn 2005, 2007). The fishery essentially ceased in 2006–07, with just 5 tows and an estimated catch of 87 kg in 2006–07, and 10 tows and 124 kg catch in 2007–08 (Figure 14). The decline of the black cardinalfish fishery here is consistent with the decline of the associated orange roughy fishery and reallocation of effort to the West Norfolk Ridge (Clark 2008).

Historically most of the black cardinalfish catch has been from target tows, at 600–1100 m depth, and mostly between January and May. In the last 2 years all catch was taken in July and August. Unstandardised catch rates have been variable. The catch rate in the bycatch fishery declined from a peak of 2.5 t/tow in 1995–96 to <0.1 t/tow in 2003–04 and 2005–06 to 2007–08. The catch rate in the target fishery peaked at 6 t/tow in 1993–94, and then declined to 1.5 t/tow in 1999–200, peaked at 4 t/tow in 2000–01, and then declined to <0.1 t/tow in 2006–07, and zero catch per tow in 2007–08 (Figure 14).

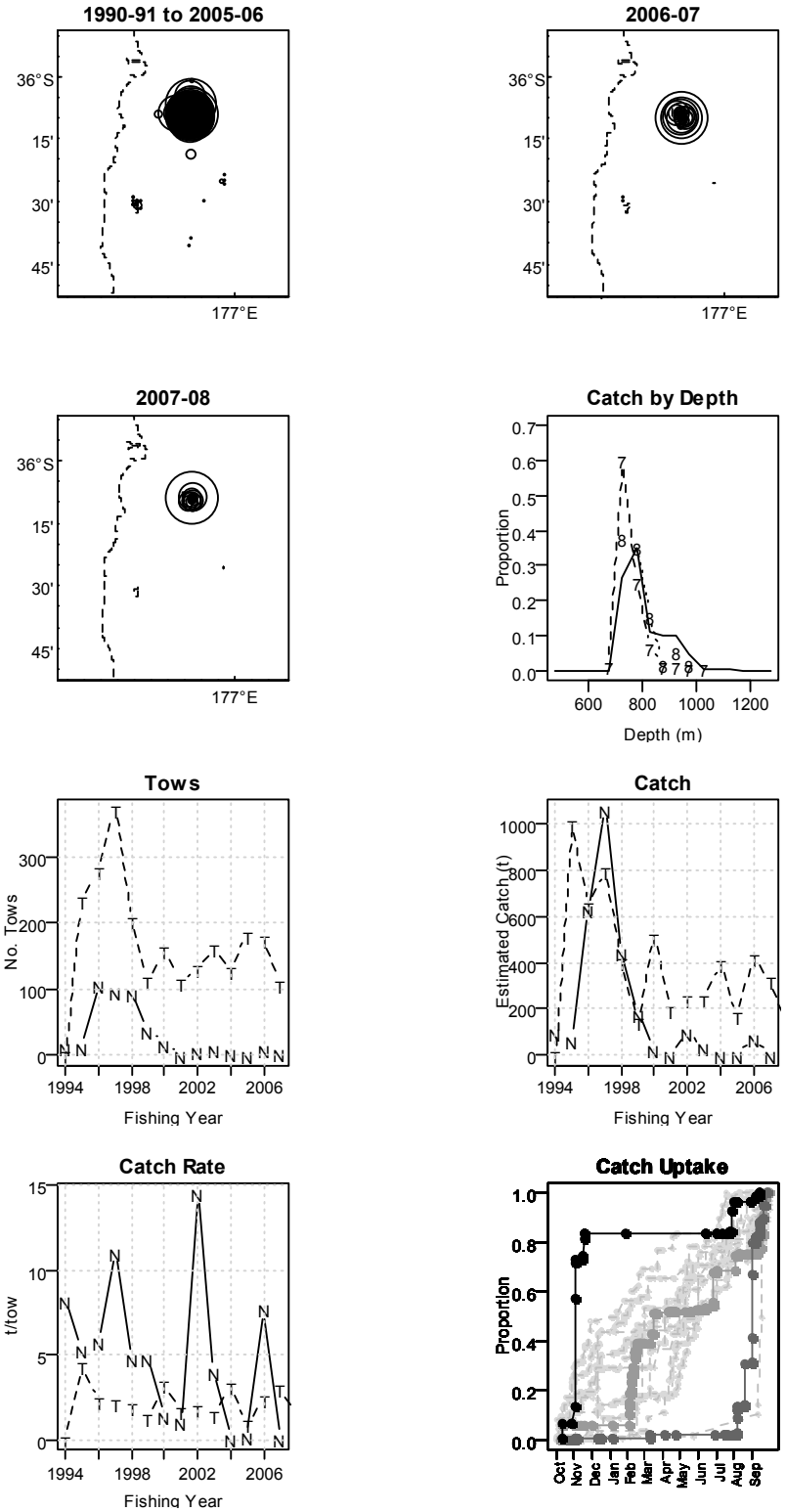

Figure 11: Statistics for the Mercury-Colville black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 85 t, 85 t and 55 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T"0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

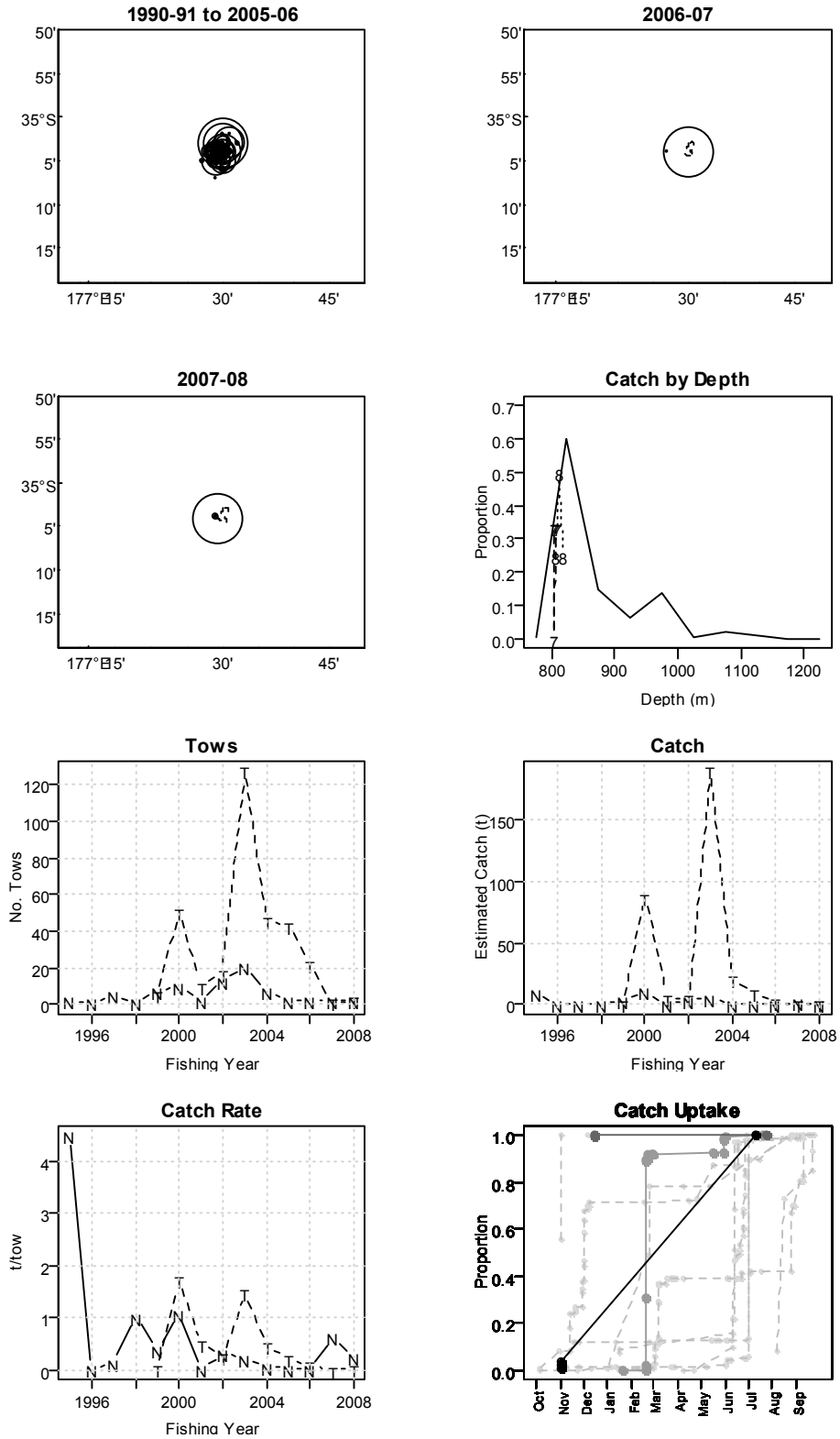

Figure 12: Statistics for the North Colville black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 50 t, 1 t and 0.5 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T")0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

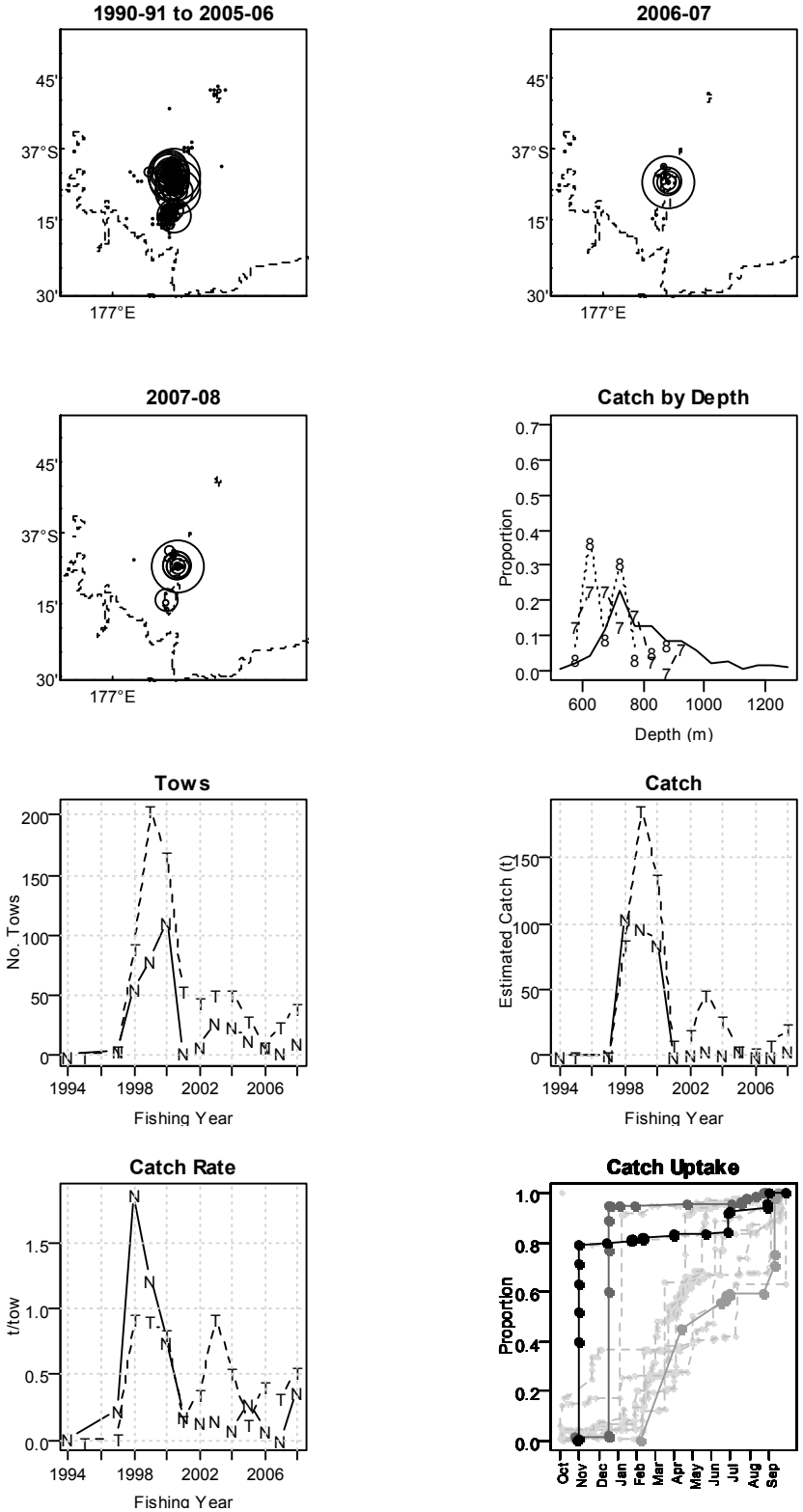

Figure 13: Statistics for the White Island black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 60 t, 5 t and 10 t). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T")0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

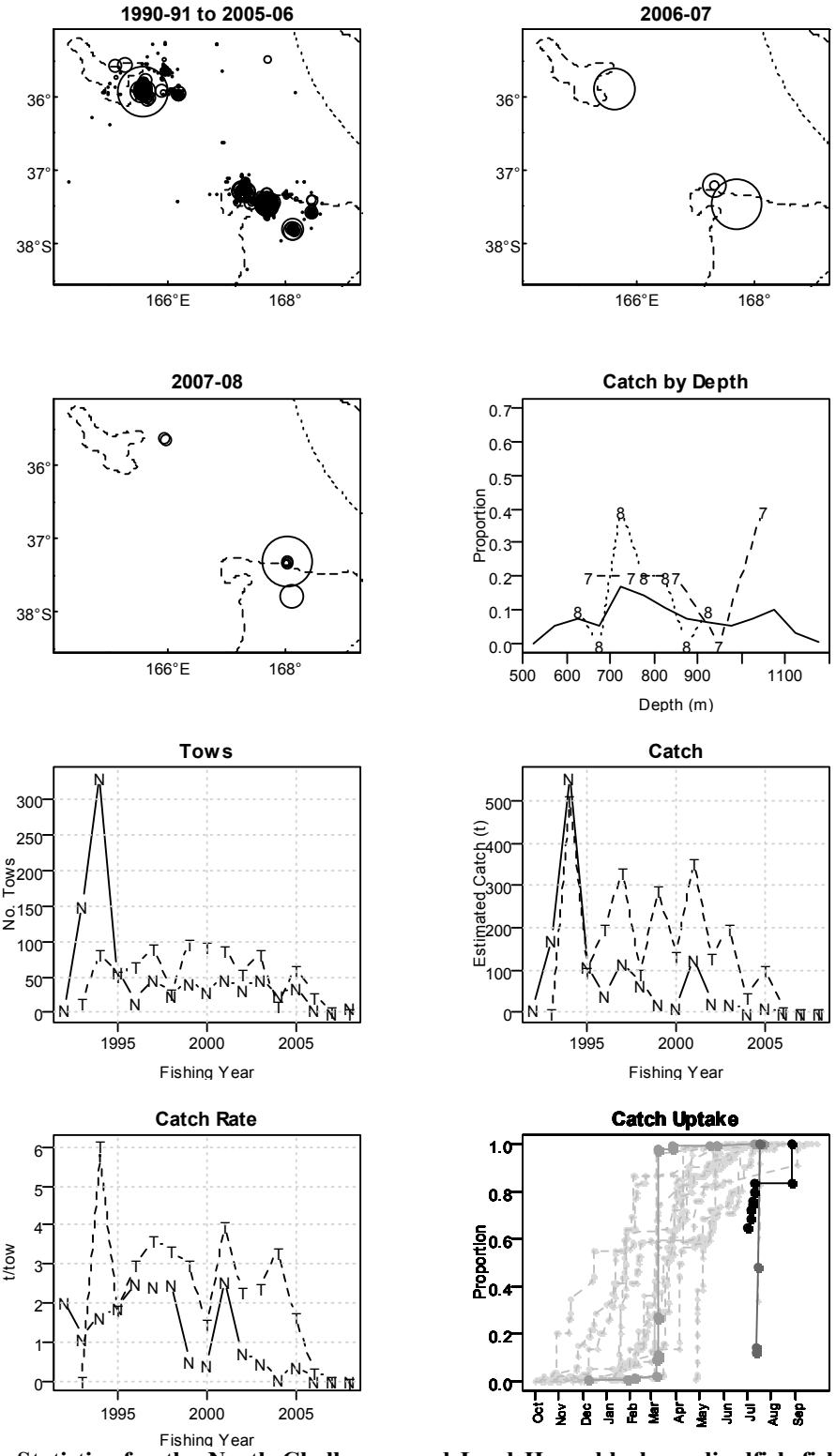

Figure 14: Statistics for the North Challenger and Lord Howe black cardinalfish fishery. The first 3 panels show the location of tows by fishing year, with circle size proportional to catch (maximum catches from top left respectively 236 t, 45 kg and 80 kg). Catch by depth shown for 2007–08 ("8"), 2006–07 ("7"), and all previous years (solid line). The number of tows, estimated catch and unstandardised catch rate are for black cardinalfish target ("T"0 and non-target tows. The catch uptake is the cumulative proportion of the annual catch by tow (points, in date order) for the fishing years 2007–08 (black), 2006–07 (dark-grey), 2005–06 (mid-grey), and previous years (light-grey).

4. CPUE ANALYSES FOR CDL 2

The previous sections have identified a trend of increasing effort (as number of tows) and targeting of black cardinalfish in CDL 2, but with an often decreasing unstandardised catch rate (t/tow). This section includes further analysis of the spatial and temporal patterns in the CDL 2 fishery, investigates the potential meaning (or not) of the reported target species, considers the use of this potential predictor in standardised CPUE analyses for black cardinalfish, and presents the results of the standardised analyses.

4.1 Fleet structure and fishing patterns

Fisheries for orange roughy have been demonstrated to show signs of serial depletion of the fish aggregations which form on features such as hills (Dunn et al. 2008). This was investigated for black cardinalfish in CDL 2 by allocating all catches to a point on an axis, which roughly followed the 800 m depth contour (Figure 15).

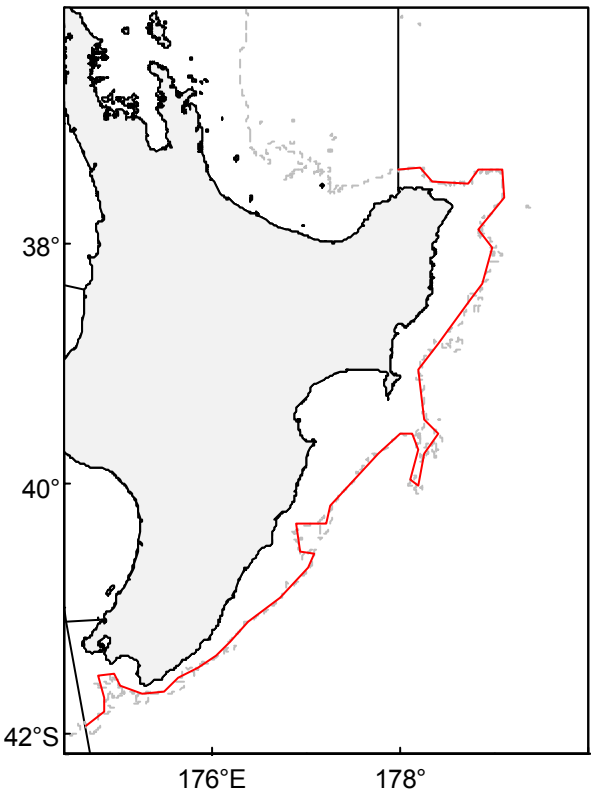

Figure 15: Location of the axis (solid line) which roughly follows the 800 m isobath (broken line) for CDL 2.

The catches by axis location clearly showed the focus of the fishery on features, specifically on the East Cape hills, Tolaga and Tuaheni hills, the Ritchie and Rockgarden hills, and Wairarapa hills (Figure 16). Although the catches from each location were variable between years, there were no signs that serial depletion of features had taken place.

There has been a change in fleet, with different vessels dominating the effort in early and later period of the fishery, but overall there was good overlap between vessels and no evidence of any 'stepwise' changes in fleet composition (Table 9).

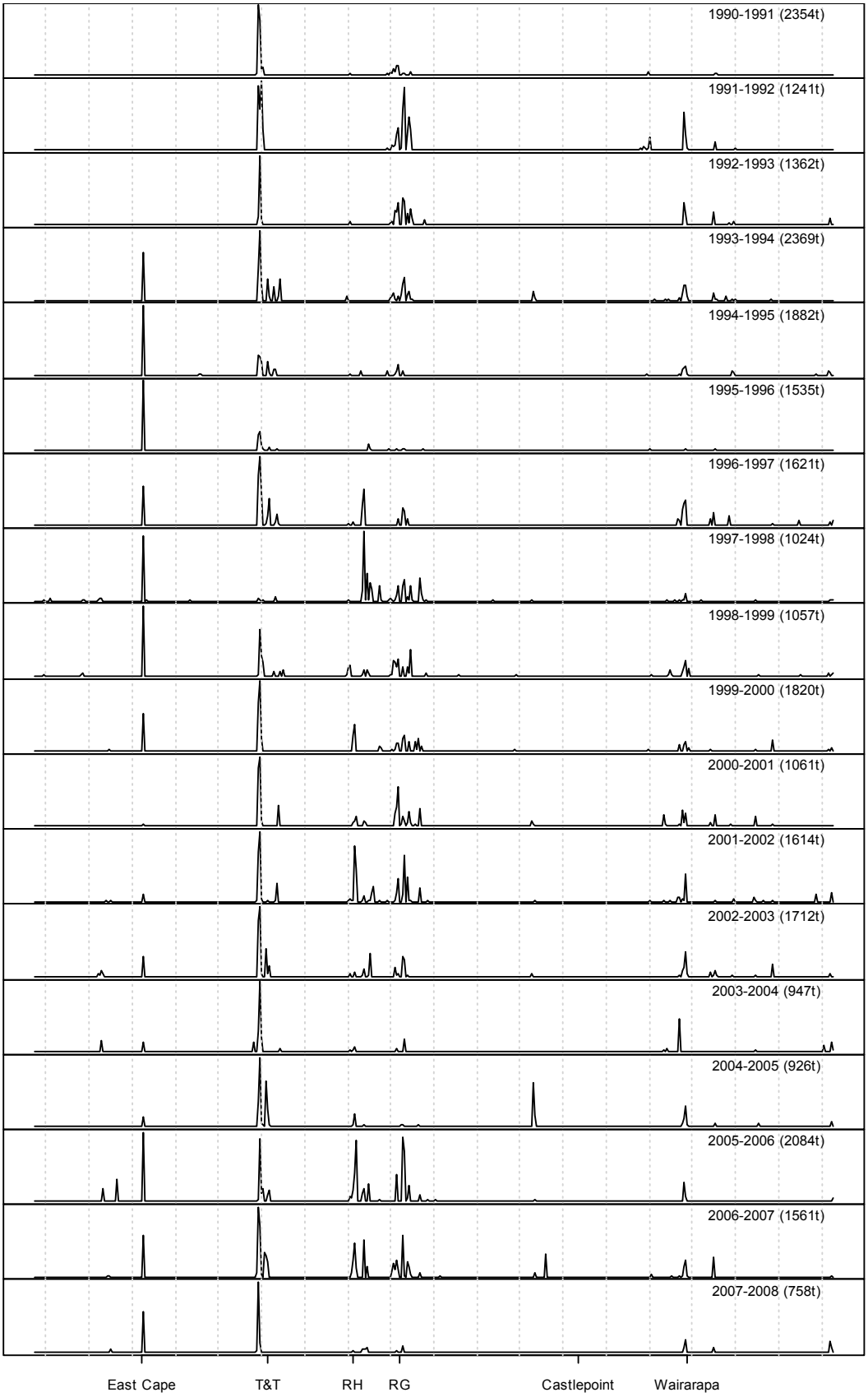

Figure 16: The proportion of annual catch (solid line) taken in CDL 2 by axis position (see Figure 15). The annual catch for each year is shown in parentheses. The approximate position of locations on the axis are indicated: "T&T", Tolaga and Tuaheni High; "RH", Ritchie hill; "RG", Rockgarden.

Table 9: Tows by vessel (labelled A to Y) and fishing year for black cardinalfish capable tows in CDL 2, after application of the vessel selection criteria.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
A	252	160	126	281	-	-	-	-	-	-
B	194	8	42	48	166	57	45	-	-	-
C	60	78	111	251	318	-	-	-	-	-
D	140	124	165	335	281	167	19	-	-	-
E	51	27	36	-	11	46	26	11	-	3
F	57	126	171	304	163	117	277	89	57	1
G	-	-	97	102	65	52	-	-	3	-
H	-	-	5	192	222	-	3	-	-	56
I	190	210	104	211	248	162	190	292	308	280
J	149	88	63	84	312	352	253	389	267	238
K	-	-	-	-	71	21	46	43	48	6
L	-	-	-	73	227	272	119	104	23	5
M	9	31	36	29	95	1	18	25	90	69
N	81	105	38	84	69	-	-	-	-	-
O	-	-	-	-	178	57	201	612	356	55
P	4	-	-	31	58	6	18	21	68	88
Q	-	-	-	-	-	-	189	227	309	173
R	-	283	357	-	10	37	84	3	98	110
S	-	-	4	154	98	53	17	95	161	175
T	-	-	-	55	4	42	20	10	59	146
U	97	137	191	304	138	114	110	55	16	106
V	-	-	-	-	73	162	213	310	268	298
W	-	-	-	-	2	74	23	63	41	138
X	-	-	-	-	-	-	-	79	254	195
Y	-	-	-	-	-	3	39	32	45	8

	2001	2002	2003	2004	2005	2006	2007	2008	Median tows per year
A	-	-	-	-	-	-	-	-	206
B	-	-	-	-	-	-	-	-	48
C	-	-	-	-	-	-	-	-	111
D	-	-	-	-	-	-	-	-	165
E	-	-	-	-	-	-	-	-	27
F	-	-	-	-	-	-	-	-	122
G	-	-	47	39	-	-	-	-	52
H	-	-	33	-	13	20	18	12	19
I	274	142	-	-	-	-	-	-	211
J	67	55	69	10	-	-	-	-	119
K	-	-	-	-	-	-	-	-	45
L	9	23	6	16	40	55	-	-	40
M	75	10	21	6	6	-	-	-	25
N	15	33	17	43	85	21	43	9	43
O	-	-	-	-	-	-	-	-	190
P	-	-	8	9	11	-	-	-	18
Q	24	12	-	-	-	-	-	-	181
R	45	41	170	120	195	164	-	-	104
S	10	-	-	-	-	-	-	135	97
T	42	83	38	2	56	-	-	-	42
U	183	205	382	82	99	353	385	60	126
V	166	152	106	64	54	56	113	162	157
W	179	196	212	190	214	150	141	84	140
X	113	164	162	121	201	136	232	140	162
Y	3	10	6	20	75	373	455	341	32

The analyses earlier in this report described a recent increase in the proportion of black cardinalfish being caught in targeted tows, and a decrease in median tow duration (e.g., Figure 5). The overall amount of black cardinalfish bycatch has shown no clear trend over time, but the proportion of other species taken as bycatch in the black cardinalfish targeted tows appears to have slowly and slightly increased (Figure 17). The bycatch of black cardinalfish in tows targeting other species (primarily orange roughy, hoki, and alfonsino) showed a stepwise decrease in 1997–98, compared to a steady decrease in the target fishery (Figure 17). This suggests that bycatch of other species may have increased slightly in the black cardinalfish target fishery over time, but black cardinalfish bycatch in other fisheries sharply declined from 1997–98. The stepwise form of the latter change suggests a change in fishing practice or catch reporting, rather than a response to a change in black cardinalfish abundance.

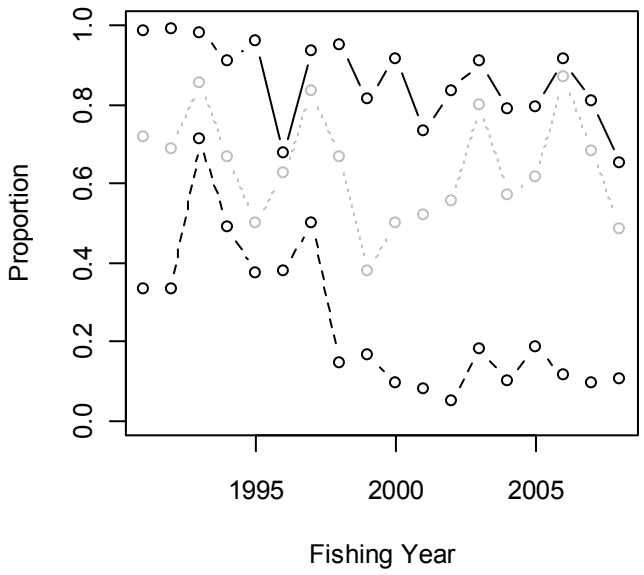

Figure 17: The median proportion of bycatch by fishing year (labelled by year-ending): solid line, proportion of black cardinalfish catch in target tows; broken black line, proportion of black cardinalfish catch in tows targeting other species; dotted grey line, proportion of black cardinalfish catch in all tows.

The meaning of the reported target species is uncertain. It may indicate genuine intent, but it might also be a function of the achieved catch, or perhaps just a "default" value. If it is not the former, then it may not be related to any specific fishing practice, and it does not make sense to use it as a predictor in a standardised analysis of CPUE.

On average, the "cardinalfish capable tows" had a median tow duration, depth, and distance from the nearest feature summit which were similar to those tows recorded as targeting black cardinalfish (Figure 18). The similarity of the overall trend to that for black cardinalfish target tows indicates that most of the "cardinalfish capable tows" were probably targeting black cardinalfish. Nevertheless, there were differences in median tow depth and distance from the nearest feature between the different target species, suggesting that reported target species could indeed indicate different tow "types".

The median tow duration was variable, but decreased across all species and then remained relatively low from 2001–02 to 2007–08 (Figure 18). The overall median depth was initially between that reported for black cardinalfish or hoki and that reported for orange roughy. The median depth got shallower over the time series, and closer to the median for black

cardinalfish target tows. This would be consistent with the increase in the proportion of black cardinalfish caught in targeted tows, as reported in Section 4.1. The distance between the tow start position and the summit of the nearest feature was initially variable, but from 1999–2000 became more distinct, with alfonsino and hoki targeted tows being closer to the summit, black cardinalfish further away (which might be inferred to be on the flanks), and orange roughy furthest away (which might be inferred to be far down the side of the feature). This pattern would be consistent with the expected depth distribution of these species, with alfonsino and hoki relatively shallow, and orange roughy relatively deep. Note that this data set was truncated at 970 m depth, and so not all of the orange roughy target tows were included.

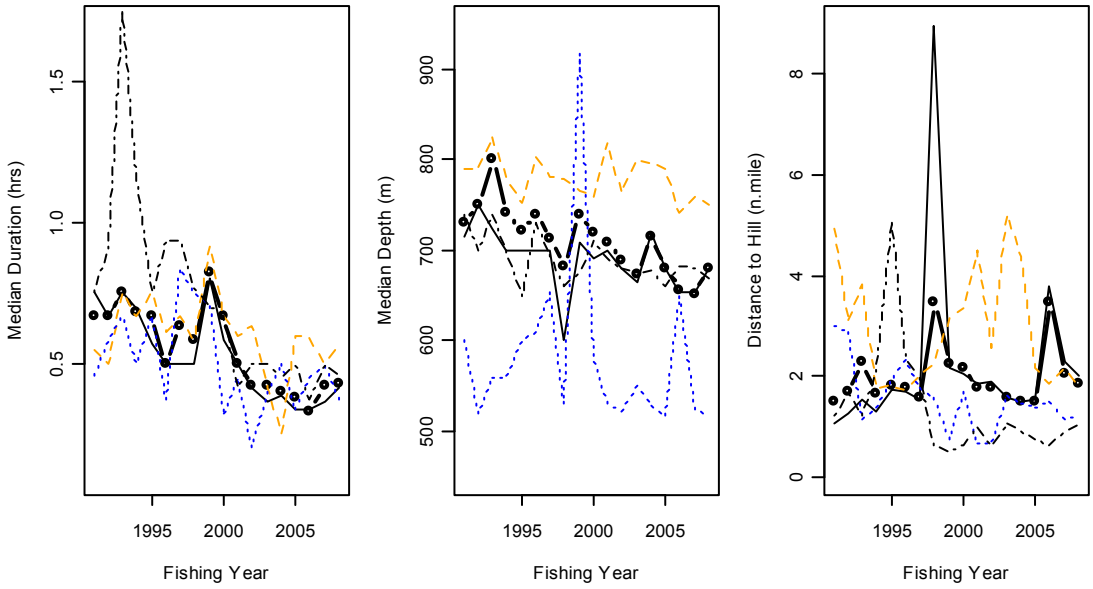

Figure 18: The median tow duration, depth, and distance from the summit of the nearest known feature, for "cardinalfish capable tows" in CDL 2. The bold line and points indicate the estimate for all tows; the black solid line the estimate for tows reported as targeting black cardinalfish; the black dot and dash line the estimate for tows reported as targeting hoki; the dotted line the estimate for tows reported as targeting alfonsino; the dashed line the estimate for tows reported as targeting orange roughy.

The patterns in tow depth, duration, and distance from feature together suggest differences in the tow "type" between different target species, which are clearer after 1999–2000. In addition, there was a reduction in the proportion of black cardinalfish caught as a bycatch, and tow lengths became shorter. We might therefore infer that the fishing fleet became more "clinical" in the way it targeted specific species since about 1999–2000. This may just be "better" fishing. It might also reflect a change in fishing plans, in response to more restrictive TACCs for orange roughy and hoki. The orange roughy TACC decreased from 4600 t to 1700 t in 2000–01, and then further to 1000 t in 2002–03. The hoki TACC decreased from 250 000 t to 200 000 t in 2001–02, then to 180 000 t in 2003–04, and then 100 000 t in 2004–05. The fishing fleet may have responded to the decrease in TACCs for these species by increasing the targeting of species where the TACC was not restrictive, such as black cardinalfish. In doing so, they may have had to improve their accuracy in targeting specific species in order to avoid over-TACC catches of orange roughy and hoki. However, this does not explain changes in the fleet as early as 1997–98. There were no TACC changes in this year, although perhaps changes in fishing practice or reporting occurred in anticipation of the introduction of the black cardinalfish TACC in 1998–99.

These changes in fishing behaviour are substantial, and support splitting the CPUE series at some point between 1997–98 and 1999–2000: the year in which the TACC was introduced, 1998–99, therefore seems a parsimonious choice. The potential change in catch reporting was found during the standardised CPUE analysis for tows targeting black cardinalfish, where the proportion of tows catching cardinalfish either dropped around 1998–99, or stepped up in 1999–2000 (Dunn 2007). Dunn speculated that this change in behaviour or catches may have been related to the introduction of the TACC in 1998–99 (this is described in the next section). For the period after 1998–99, *target species* seems to have some meaning, and therefore it seems reasonable to consider it as a potential predictor. Before 1998–99, *target species* has less clear meaning and may even be misleading, and it therefore seems best to exclude it.

4.2 Index for 1990–91 to 2007–08

Because the CPUE time series is being split in 1998–99, the standardised CPUE analysis using the full time series (1990–91 to 2007–08) is described here only briefly to demonstrate the initial steep decline in standardised CPUE and change in non-zero catches noted by Dunn (2007).

Target species was excluded as a potential predictor. The binomial model explained 20.3% and had the predictors *fishing year*, *subarea*, *vessel*, and *depth* (Figure 19). The lognormal model explained 15.3% and had the predictors *fishing year*, *vessel*, and *subarea*. The predicted year effect was broadly similar to that obtained by Dunn (2007), even though Dunn used target tows, and this analysis used "cardinalfish capable tows". The combination of high binomial and lognormal year effects at the start of the time series results in a very high value of the combined index, followed by a steep decline (Figure 19). The higher binomial year effects from 2000–01 to 2003–04 result in a step-up in the combined index with a peak in 2001–02, followed by a continuing decline. The decline after the initial steep decline, between 1993–94 and 2007–08, was about 80% in the normal model and about 76% in the combined model.

4.3 Index for 1998–99 to 2007–08 including *target species*

After data grooming and applying the data selection criteria, the data set included 9450 tow records. Eight vessels were included in the data set, with good overlap between vessels (Table 10). Data were also restricted to seven subareas (Table 11), and 4 target species (Table 12). After applying the data selection criteria, the data set included 51% of the tows and 77% of the black cardinalfish catch.

Table 10: Tows by vessel key and fishing year as used for the 1998–99 to 2007–08 *target species* index, after application of the data selection criteria. "–", zero tows.

Vessel key	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
321	204	208	167	114	–	–	–	–	–	–
5250	49	103	20	74	31	2	48	–	–	–
8601	125	183	83	107	68	50	23	23	84	104
4849	88	103	28	37	110	82	136	111	–	–
8700	11	55	85	84	91	61	101	69	56	25
12600	97	131	64	118	128	90	159	127	203	102
5663	5	94	166	188	359	72	77	334	379	53
11138	14	1	–	7	–	14	65	345	405	280

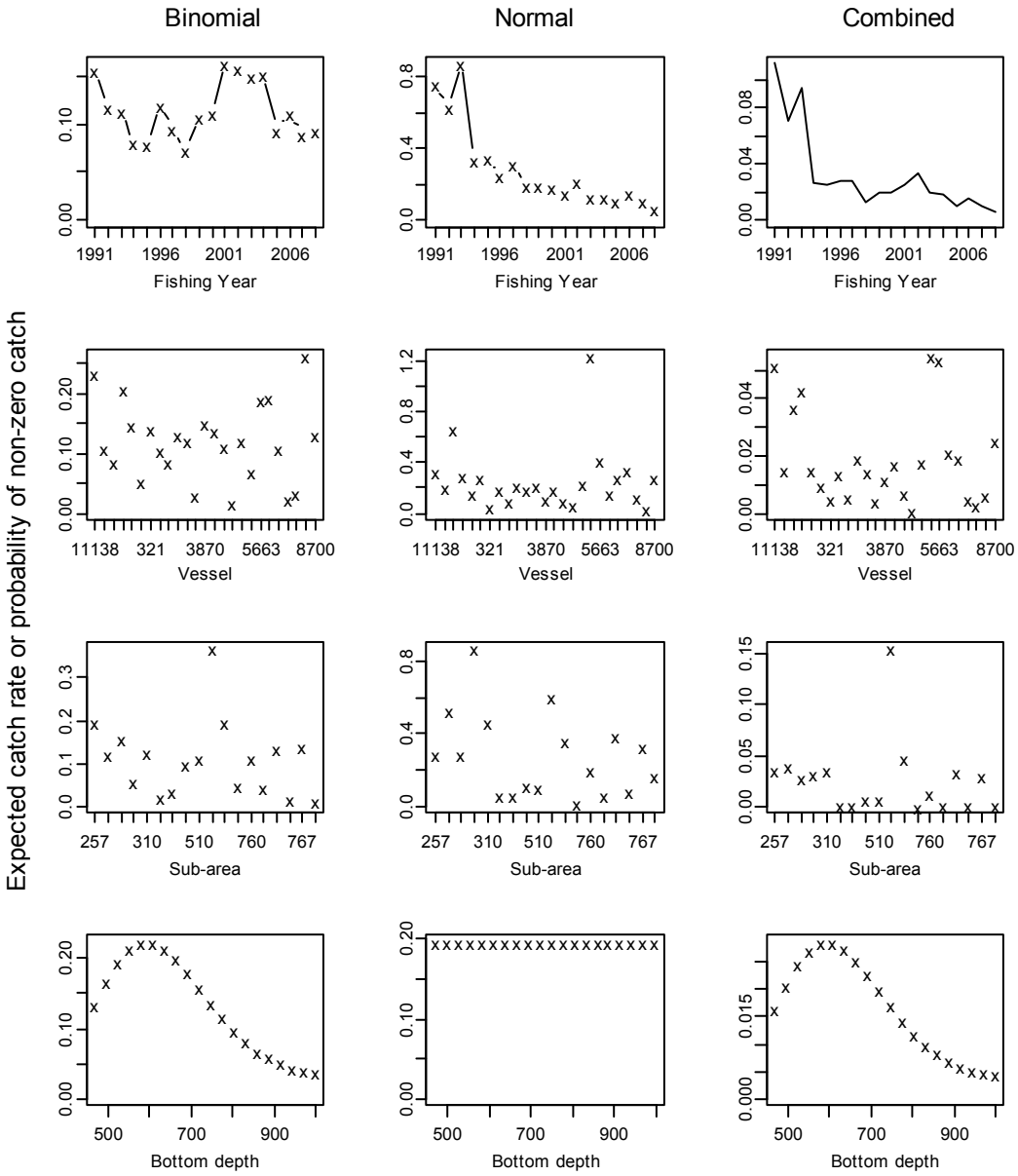

Figure 19: Model predictions for the 1990–91 to 2007–08 index, by *fishing year* (labelled as year ending, i.e., 1991 means 1990–91) v*essel*, subarea, and *bottom depth*, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values.

About 70% of the tows caught no black cardinalfish (Figure 20), and the unstandardised catch rate had no clear overall trend, but there were peaks in catch rate in 2001–02 and 2005–06 (Figure 20).

The dependent variable was log(t/tow), and the final binomial model explained 15.0% of the deviance (Table 13), and the non-zero catch (normal) model 10.0% of the deviance (Table 14). None of the interactions tested were included in either model.

The fit of the model was reasonable (Figure 21). While most of the data fitted the model, the small departures towards the ends of the normal model quantile plot indicated the model did not describe all of the extremes of the catch rate.

Table 11: Tows by subarea and fishing year as used for the 1998–99 to 2007–08 *target species* index, after application of the data selection criteria.

Subarea code	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
280	293	398	174	212	216	86	154	298	223	91
767	31	78	84	87	73	58	87	83	59	34
542	78	111	136	123	182	90	131	99	233	99
271	37	35	33	41	45	14	76	32	115	21
257	60	115	27	48	74	37	51	125	127	124
574	64	114	81	127	90	42	56	284	202	102
310	30	27	78	91	107	44	54	88	168	93

Table 12: Tows by reported target species and fishing year as used for the 1998–99 to 2007–08 *target species* index, after application of the data selection criteria.

Target species	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
ORH	378	588	180	158	115	95	213	215	171	176
HOK	23	57	96	90	82	62	65	46	37	21
CDL	171	209	305	443	508	188	295	644	766	286
BYX	21	24	32	38	82	26	36	104	153	81

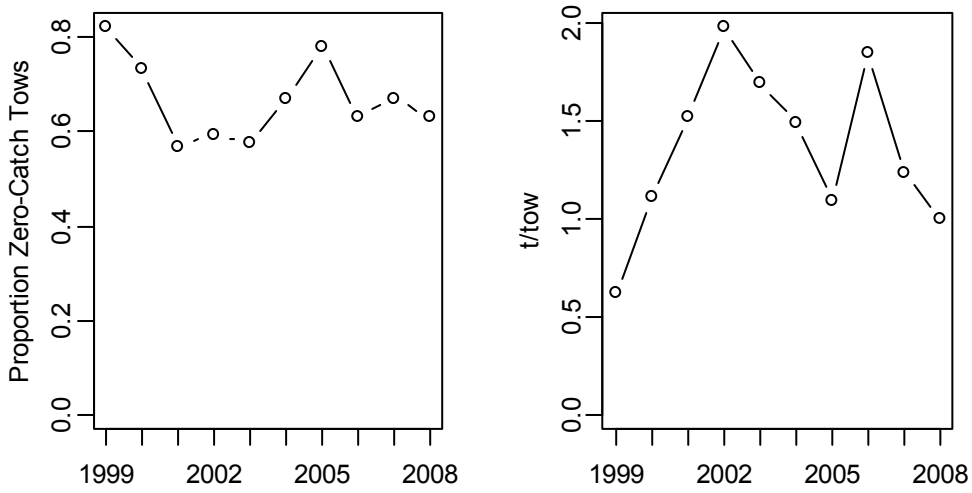

Figure 20: The proportion of tows with non-zero catch of black cardinalfish (left panel) and the unstandardised catch rate per tow (total catch divided by total number of tows (including zero catch tows), right panel) for the 1998–99 to 2007–08 *target species* index.

Table 13: Predictor and percentage of deviance explained for the final binomial model fit for the 1998–99 to 2007–08 *target species* index. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	% dev. expl.	Add % dev. expl.
Fishing year	1	8	9 102	2.2	2.2
Target species	2	3	8 224	11.8	9.5
Vessel	4	7	7 935	15.0	3.3

Table 14: Predictor and percentage of deviance explained for the final normal model fit for the 1998–99 to 2007–08 *target species* index. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	% dev. expl.	Add % dev. expl.
Fishing year	1	8	11 891	1.2	1.2
Vessel	2	7	11 726	8.2	7.0
Target species	3	3	11 683	10.0	1.8

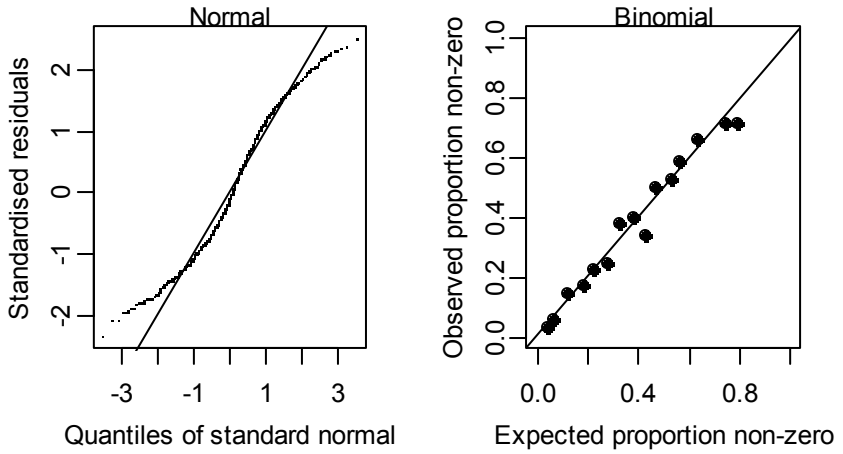

Figure 21: Residuals (left panel) and normal quantile plot (right panel) for the fit for the 1998–99 to 2007–08 *target species* index.

The model indicated a roughly 4-fold difference in success rate and roughly 7-fold difference in subsequent non-zero catch rate between vessels (Figure 22).

The fishing success and subsequent non-zero catch rate were highest for the tows reported as targeting black cardinalfish, followed by hoki, alfonsino, and then orange roughy (Figure 22). The difference between the combined catch rates was large, with black cardinalfish nearly 20 times higher than orange roughy.

The year effect indicated an increase in fishing success from 1998–99 to 2000–01, and then a decline from 2000–01 to 2004–05 (Figure 22). The non-zero catch rate declined substantially between 1998–99 and 1999–2000, after which is declined steadily, with small peaks in 2001–02 and 2005–06. In the combined index, the relatively low fishing success and high non-zero catch rate in 1998–99 and 1999–2000 effectively cancelled each other out, so that the combined index showed a relatively smooth trend, declining steadily over the time series until 2005–06, when there was a small peak in catch rate, followed by a decline to 2007–08. The standardised model had a large influence on the CPUE trend, and the estimated year effect was dramatically different to the unstandardied trend (see Figure 20).

The bootstrap procedure estimated the high coefficient of variation (c.v.) of 0.54-0.63 (Table 15). This variability came largely from the non-zero (normal) catch model. The c.v.s could be reduced substantially by excluding the *target species* or the *vessel* predictor from the model. Further analysis of the data revealed that a single vessel (vessel key "8700") caught almost all cardinalfish as a bycatch in the hoki target fishery, unlike any other vessel (Tables 16 & 17), yet had the highest vessel coefficients (non-zero catch rate) in the model (Figure 22). Excluding this vessel reduced the proportion of the black cardinalfish catch remaining in the final index only slightly, but reduced the c.v.s of the year index substantially (see Sections 4.4 and 4.7).

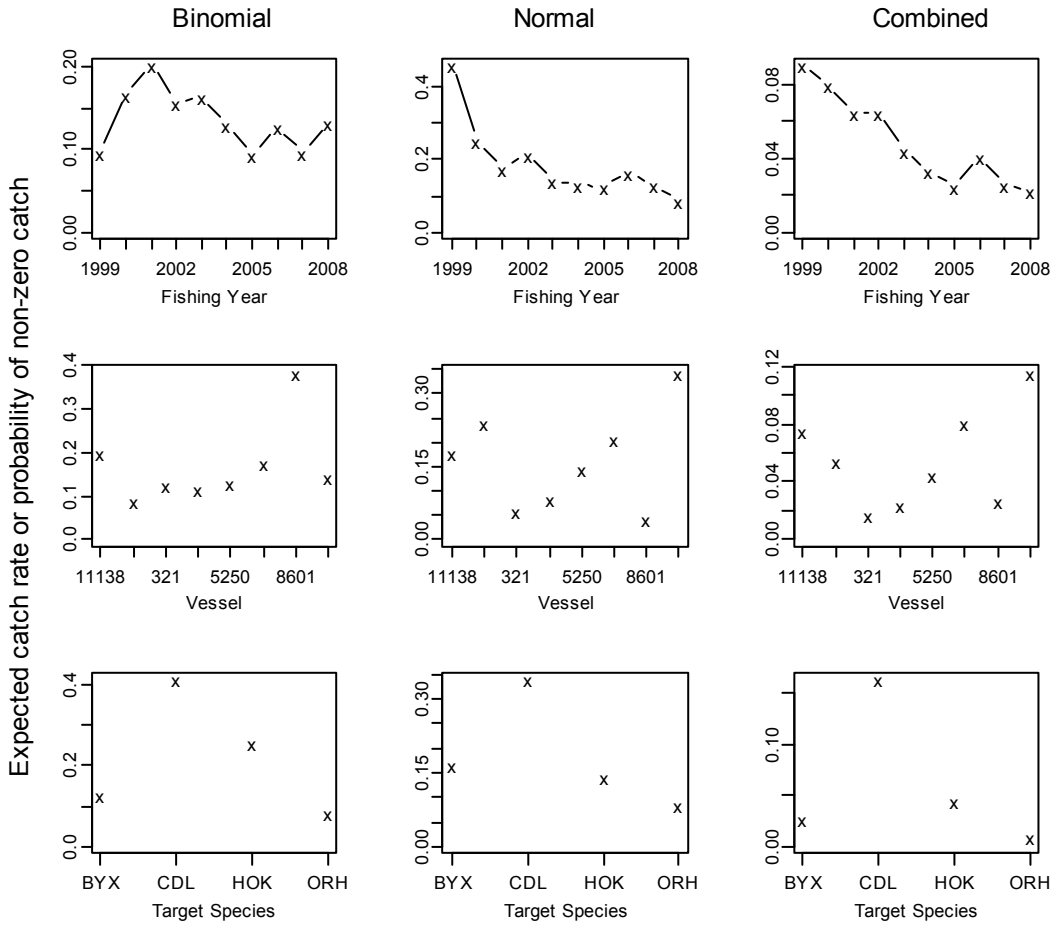

Figure 22: Model predictions for the 1998–99 to 2007–08 *target species* index, by *fishing year* (labelled as year ending, i.e., 1991 means 1990–91) v*essel*, and *target species*, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values.

Table 15: Year index and estimated coefficient of variation (c.v.) for the 1998–99 to 2007–08 *target species* index.

	Combined		Non-zero (normal)		Binomial	
	Index	c.v.	Index	c.v.	Index	c.v.
1998–99	1.00	0.57	1.00	0.61	0.48	0.18
1999–00	0.88	0.53	0.55	0.57	0.83	0.15
2000–01	0.71	0.54	0.38	0.57	1.00	0.15
2001–02	0.71	0.52	0.47	0.57	0.78	0.15
2002–03	0.49	0.55	0.31	0.57	0.81	0.15
2003–04	0.36	0.59	0.28	0.60	0.64	0.18
2004–05	0.27	0.59	0.27	0.59	0.47	0.17
2005–06	0.46	0.56	0.36	0.59	0.63	0.16
2006–07	0.28	0.58	0.28	0.60	0.47	0.16
2007–08	0.25	0.60	0.19	0.61	0.65	0.17

Table 16: Proportion of the number of non-zero tows by vessel and reported target species, with the total number of tows completed. "–", zero tows.

Target species	11138	12600	321	4849	5250	5663	8601	8700
BYX	30	2	1	–	11	44	31	2
CDL	449	107	136	144	74	770	162	17
HOK	5	–	9	–	–	–	–	165
ORH	4	48	30	14	10	1	177	–
Tows	488	157	176	158	95	815	370	184

Table 17: The number of non-zero catch tows by vessel and fishing year.

Fishing year	321	4849	5250	5663	8601	8700	11138	12600
1999	20	14	7	1	46	1	1	16
2000	40	9	24	55	73	18	–	14
2001	64	3	5	96	38	40	–	19
2002	52	7	22	97	63	31	1	23
2003	–	36	14	193	38	26	–	28
2004	–	32	2	27	34	15	2	10
2005	–	46	21	24	5	13	10	15
2006	–	11	–	184	10	8	149	10
2007	–	–	–	123	27	24	184	13
2008	–	–	–	15	36	8	141	9
Total	176	158	95	815	370	184	488	157

4.4 Index for 1998–99 to 2007–08 including *target species* and excluding vessel "8700"

After data grooming and applying the data selection criteria, the data set included 6421 tow records. Seven instead of eight vessels previously included were now in the data set, with good overlap between vessels (Table 18). Data were also restricted to six of the seven previous subareas (Table 19), and three of the four previous target species (Table 20). After applying the data selection criteria, the data set included 51% of the tows and 76% of the black cardinalfish catch.

Table 18: Tows by vessel key and fishing year as used for the 1998–99 to 2007–08 *target species* index, after excluding vessel "8700" and application of the data selection criteria. "–", zero tows.

Vessel key	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
321	204	208	156	100	–	–	–	–	–	–
5250	44	103	20	74	31	2	47	–	–	–
8601	116	153	59	92	60	47	21	19	81	98
4849	88	103	28	37	110	82	136	111	–	–
12600	92	130	64	118	128	90	157	121	202	97
5663	4	89	162	188	359	71	76	332	379	53
11138	7	–	–	5	–	9	50	339	398	271

About two-thirds of the tows caught no black cardinalfish, and the unstandardised catch rate had no clear overall trend, but peaks in catch rate in 2001–02 and 2005–06 (Figure 23). The dependent variable was log(t/tow), and the final binomial model explained 16.0% of the deviance (Table 21), and the non-zero catch (normal) model 10.3% of the deviance (Table 22). None of the interactions tested were included in either model. The fit of the model was reasonable (Figure 24). Whilst most of the data fitted the model, the small departures towards the ends of the normal model quantile plot indicated the model did not describe all of the extremes of the catch rate.

Table 19: Tows by subarea and fishing year as used for the 1998–99 to 2007–08 *target species* index, after excluding vessel "8700" and application of the data selection criteria.

Subarea	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
280	293	398	173	212	208	85	151	298	222	91
542	78	105	110	109	180	90	118	99	233	99
271	37	35	33	36	45	14	70	32	115	21
257	60	115	27	48	74	37	51	125	127	124
574	64	109	78	123	88	42	55	284	201	102
310	23	24	68	86	93	33	42	84	162	82

Table 20: Tows by reported target species and fishing year as used for the 1998–99 to 2007–08 *target species* index, after excluding vessel "8700" and application of the data selection criteria.

Target species	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
ORH	364	557	153	141	105	91	180	191	159	161
CDL	170	205	304	435	508	186	280	627	752	281
BYX	21	24	32	38	75	24	27	104	149	77

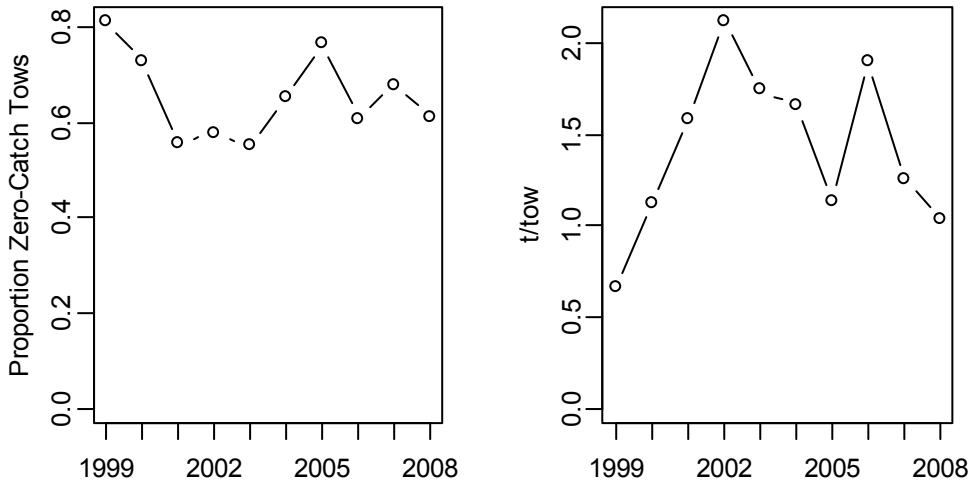

Figure 23: The proportion of tows with non-zero catch of black cardinalfish (left panel) and the unstandardised catch rate per tow (total catch divided by total number of tows (including zero catch tows), right panel) for the 1998–99 to 2007–08 *target species* index, after excluding vessel "8700".

Table 21: Predictor and percentage of deviance explained for the final binomial model fit for the 1998–99 to 2007–08 *target species* index after excluding vessel "8700". Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	% dev. expl.	Add % dev. expl.
Fishing year	1	8	8 112	2.4	2.4
Target species	2	2	7 336	11.8	9.4
Vessel	3	6	7 000	16.0	4.2

Table 22: Predictor and percentage of deviance explained for the final normal model fit for the 1998–99 to 2007–08 *target species* index after excluding vessel "8700". Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	% dev. expl.	Add % dev. expl.
Fishing year	1	8	10 867	1.5	1.5
Vessel	2	6	10 712	8.6	7.1
Target species	3	2	10 673	10.3	1.8

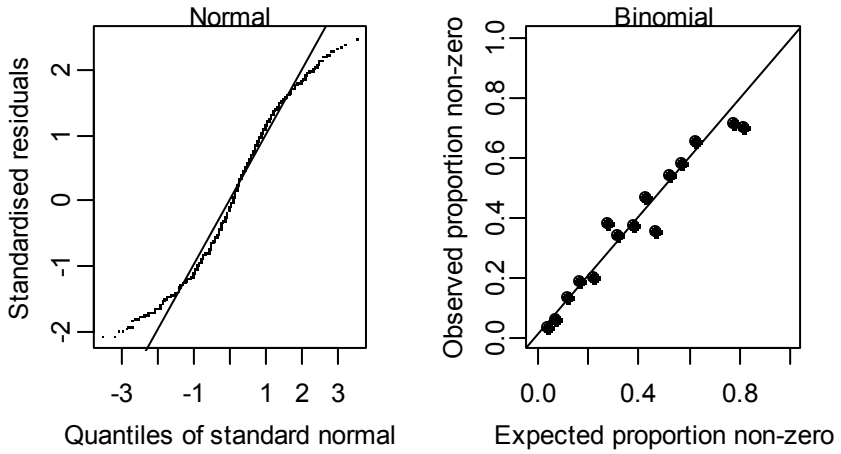

Figure 24: Residuals (left panel) and normal quantile plot (right panel) for the fit for the 1998–99 to 2007–08 *target species* index after excluding the vessel "8700".

The model indicated a roughly 6-fold difference in success rate, a roughly 7-fold difference in non-zero catch rate between vessels, resulting in a roughly 5-fold combined difference between the best and worst performing vessels in the combined model (Figure 25).

The fishing success and subsequent non-zero catch rate were highest for the tows reported as targeting black cardinalfish, followed by alfonsino, and then orange roughy (Figure 25). The difference between the combined catch rates was large, with black cardinalfish target tows having a catch rate nearly 10 times higher than orange roughy target tows.

The year effect indicated an increase in fishing success from 1998–99 to 2000–01, and then a decline from 2000–01 to 2004–05 (Figure 25). The non-zero catch rate declined substantially between 1998–99 and 1999–2000, after which is declined steadily, with small peaks in 2001–02 and 2005–06. In the combined index, the relatively low fishing success and high non-zero catch rate in 1998–99 and 1999–2000 effectively cancelled each other out, so that the combined index showed a relatively smooth trend, declining steadily over the time series until 2005–06, when there was a small peak in catch rate, followed by a decline to 2007–08. The year trend was very similar to that given in the previous index (Section 4.3), however the c.v.s were reduced from 0.52–0.60 to 0.39–0.48 (see Section 4.7).

4.5 Index for 1998–99 to 2007–08 excluding *target species*

The data set obtained after data grooming and applying the data selection criteria (section 4.3) was refitted to the binomial and normal models without target species. This data set included vessel "8700".

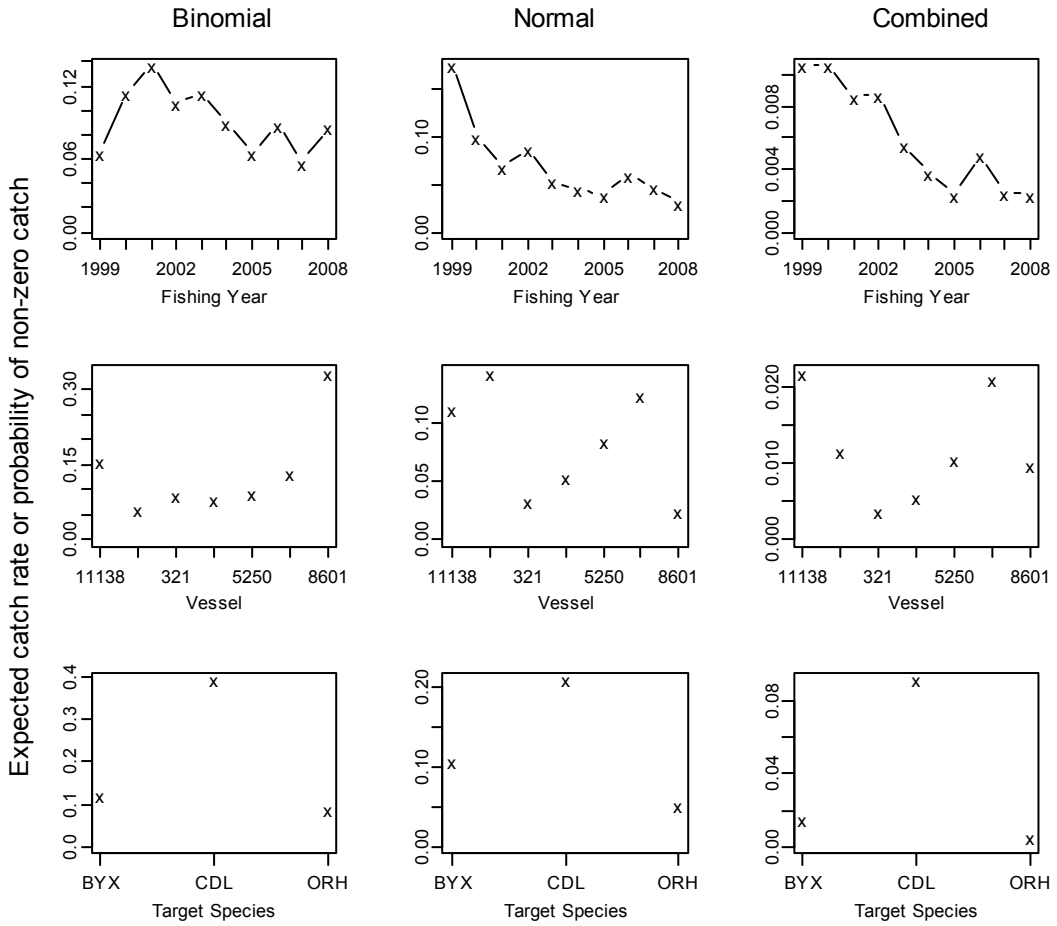

Figure 25: Model predictions for the 1998–99 to 2007–08 *target species* index after excluding vessel "8700", by *fishing year* (labelled as year ending, i.e., 1991 means 1990–91) v*essel*, subarea, and *target species*, for the binomial, normal, and combined model, made with all other predictors set to the median (fixed) values.

Excluding the predictor *target species*, which explained 11.8% of the deviance, made the total deviance explained by the binomial model drop from 15.0% to 12.6% (Table 23). The normal model without *target species* explained 7.0% of the deviance (Table 24), dropping from 10.0% when including *target species* (see Table 14). Therefore *target species* had an effect on both whether black cardinalfish was caught, and the amount caught. The predictors accepted into the binomial model when *target species* was excluded were those identified as potentially characteristic of tow types, such as *depth* and *distance from hill* (Figure 18, Table 23).

Table 23: Predictor and percentage of deviance explained for the final binomial model fit for the 1998–99 to 2007–08 excluding *target species* index. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	%dev.expl	Add%dev.expl
Fishing year	1	8	9 102	2.2	2.2
Vessel	2	7	8 610	7.7	5.4
Subarea	3	6	8 394	10.1	2.5
Depth	4	3	8 263	11.6	1.5
Distance from hill	5	3	8 178	12.6	1.0

Table 24: Predictor and percentage of deviance explained for the final normal model fit for the 1998–99 to 2007–08 excluding *target species* index. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	%dev.expl	Add%dev.expl
Fishing year	1	8	11 891	1.2	1.2
Vessel	2	7	11 726	8.2	7.0

The residuals indicated that the fits of the normal models were very similar for the models with or without *target species* (Figures 24 & 26).

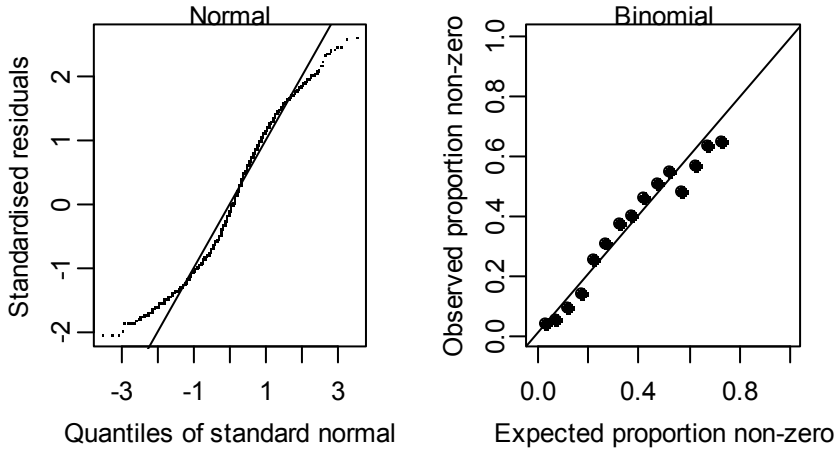

Figure 26: Residuals (left panel) and normal quantile plot (right panel) for the fit for the 1998–99 to 2007–08 excluding *target species* index.

Both the binomial and normal model year effects including *target species* were subtly different from the model excluding *target species*, and as a result the year effects in the combined models were different (Figures 25 & 27). If *target species* is a true reflection of fishing pattern, and the proportion of tows by *target species* in each year's commercial catch is constant, then excluding *target species* will not affect the year index. If the proportion varies from year to year and *target species* is excluded, then the effect will contribute to the true year index and cause bias. Conversely, there is often doubt about the meaning of the reported target species, as in reality it may simply reflect human behaviour and/or legal reporting requirements for the fishery. Although some of the *target species* effect may have been encompassed by the predictors *vessel*, *subarea*, *depth*, and *distance from hill*, the year index was clearly affected by excluding *target species.*

4.6 Index for 1990–91 to 1997–98

The 1990-91 to 1997-98 data were similarly groomed and after applying the data selection criteria 4844 tow records were included in the standardised CPUE analyses, with seven vessels, seven subareas and three target species (Tables 25–27). Compared to the initial data set, this selection included 34% of the tows and 65% of the black cardinalfish catch.

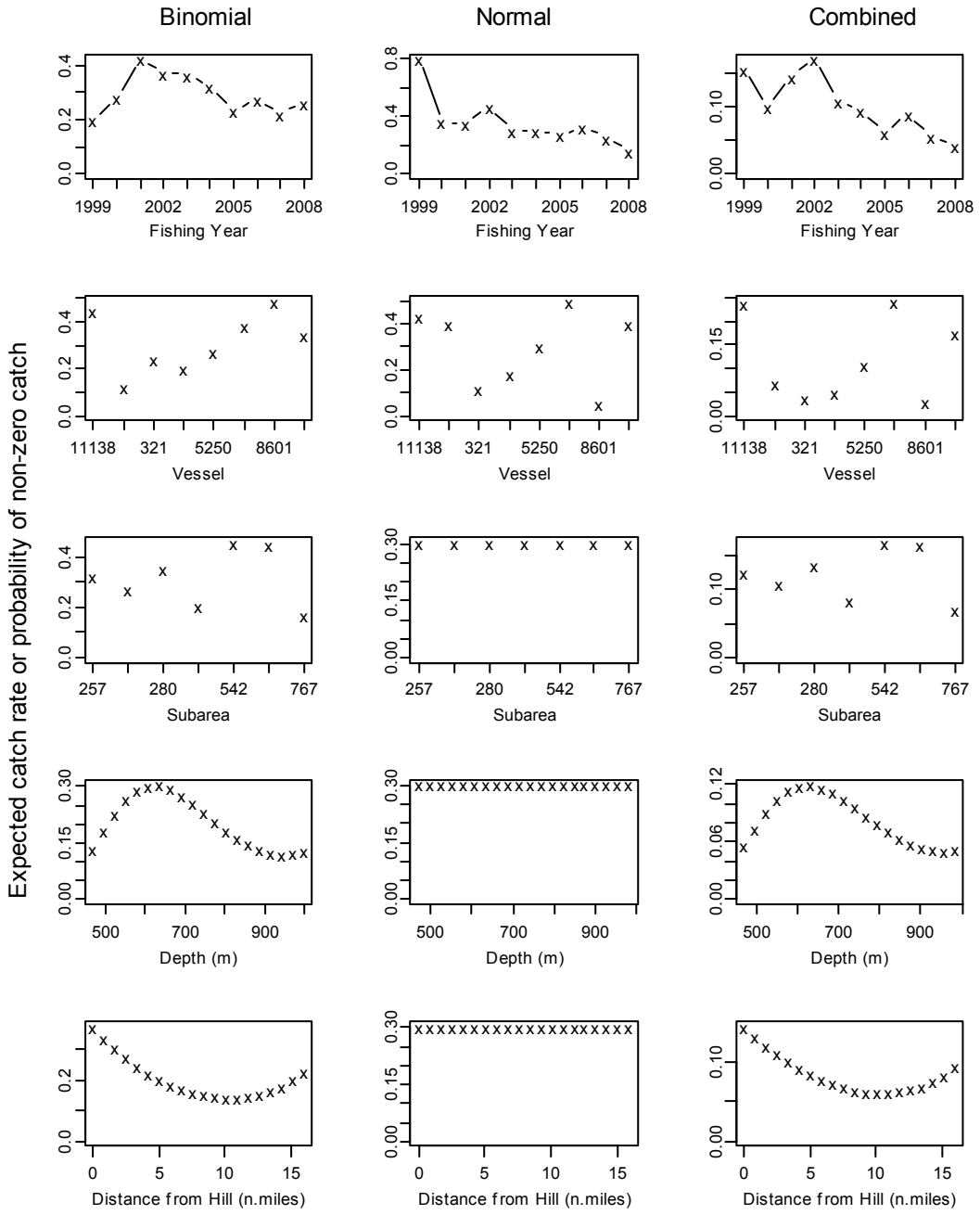

Figure 27: Model predictions for the 1998–99 to 2007–08 excluding *target species* index, by *fishing year* (labelled as year ending, i.e., 1991 means 1990–91) v*essel*, subarea, *depth*, and *distance from the nearest hill*, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values.

About 70% of the tows caught no black cardinalfish (Figure 28) and the unstandardised catch rate shows there was a steep drop in 1991–92 and then no trend or a slow decline over the period 1991–92 to 1997–98 (Figure 28).

The final binomial and normal models explained 11.4% and 24.6% of the deviance respectively (Tables 28 & 29). An interaction between *fishing year* and *subarea* was included in the normal model.

Table 25: Tows by vessel key and fishing year as used for the 1990–91 to 1997–98 index, after application of the data selection criteria. "–", zero tows.

Vessel key	1991	1992	1993	1994	1995	1996	1997	1998
3926	144	73	101	212	–	–	–	–
4849	–	171	190	–	9	35	74	–
5663	76	67	92	192	57	72	82	29
804	21	45	91	236	72	58	88	30
321	138	128	71	112	198	135	126	182
1195	126	48	39	60	153	258	147	216
8601	–	–	–	–	53	90	83	164

Table 26: Tows by subarea and fishing year as used for the 1990–91 to 1997–98 index, after application of the data selection criteria. "–", zero tows.

Subarea code	1991	1992	1993	1994	1995	1996	1997	1998
767	79	68	117	133	31	11	33	44
280	243	345	342	302	167	129	150	235
542	161	36	42	94	86	132	153	26
574	16	59	51	30	18	13	40	67
310	4	21	22	114	101	47	104	27
271	2	3	10	33	20	35	33	2
257	–	–	–	106	119	281	87	220

Table 27: Tows by reported target species and fishing year as used for the 1990–91 to 1997–98 index, after application of the data selection criteria.

Target species	1991	1992	1993	1994	1995	1996	1997	1998
ORH	229	421	465	599	307	240	199	440
CDL	266	108	110	170	143	394	320	175
BYX	10	3	9	43	92	14	81	6

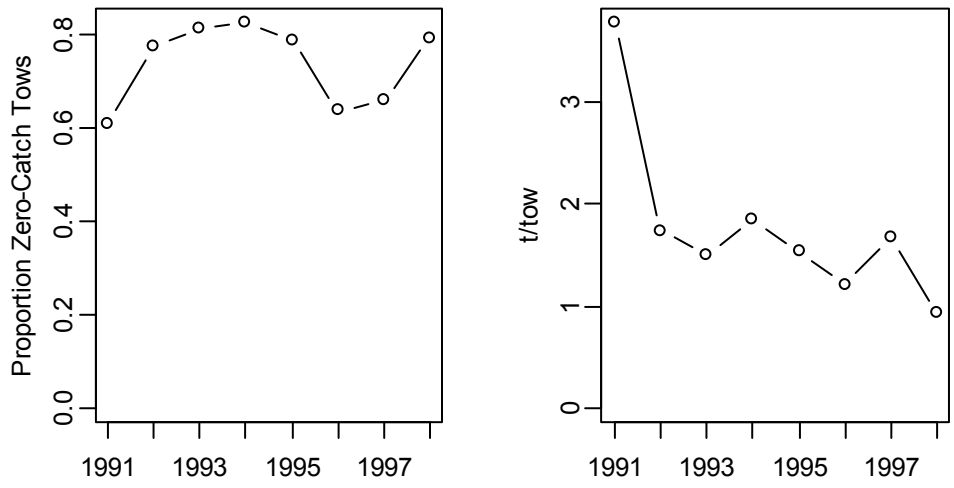

Figure 28: The proportion of tows with non-zero catch of black cardinalfish (left panel) and the unstandardised catch rate per tow (total catch divided by total number of tows (including zero catch tows), right panel) for the 1990–91 to 1997–98 *target species* index.

Table 28: Predictor and percentage of deviance explained for the final binomial model fit for the 1990–91 to 1997–98 index. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	%dev.expl	add%dev.expl
Fishing year	1	3	5 381	3.0	3.0
Depth	2	6	5 073	8.7	5.7
Subarea	3	3	4 933	11.4	2.8

Table 29: Predictor and percentage of deviance explained for the final normal model fit for the 1990–91 to 1997–98 index. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	%dev.expl	add%dev.expl
Fishing year	1	6	6 178	6.0	6.0
Vessel	2	6	6 029	17.3	11.4
Subarea	3	6	6 016	19.0	1.7
Fishing year : subarea	4	37	6 001	24.6	5.6

The year indices for subareas were quite variable, with subareas 257, 271, 310, 574, and 542 showing a decline between about 1993–94 and 1997–98, but subareas 280 and 767 showing no trend, or possibly an increase over the same period (Figure 29). The index will be weighted towards subareas 280 and 542, which included most of the tows, and least weighted towards subareas 271 and 574 (Table 30). Subarea 257 was absent until 1993–94, and then effort in this subarea peaked in 1995–96. Conversely, effort in subarea 767 decreased over the time series.

There were therefore some similarities in the year trend from the various subareas, but also differences in the amount of tows completed in each area from year to year. If black cardinalfish moved between subareas over time, then an analysis of a single subarea (Dunn 2007) might not reflect total stock abundance. The subarea trends do not suggest a series of sequential depletions, and so might indeed indicate variable distribution. Whilst it may be interesting to know that fish distribution and local abundances could be variable, subarea indices could not actually be used in a stock assessment, unless the model accounted for these movements. This did not seem practicable for black cardinalfish. A fishing year : subarea interaction would therefore be difficult to use, and potentially even invalid. In addition, the 5.6% additional deviance explained by the interaction required 37 additional degrees of freedom, increasing the chance of model over-fitting (see Table 29). It was therefore considered prudent to exclude this interaction.

Table 30: Number of non-zero catch tows by subarea and fishing year in the 1990–91 to 1997–98 index.

Fishing year	257	271	280	310	542	574	767
1991	0	1	64	3	86	3	40
1992	0	0	69	10	16	5	19
1993	0	1	57	8	18	7	18
1994	19	11	38	23	34	1	16
1995	30	12	23	17	28	1	3
1996	97	9	42	14	70	1	2
1997	16	12	49	28	73	21	6
1998	25	1	53	8	5	36	0
Total	187	47	395	111	330	75	104

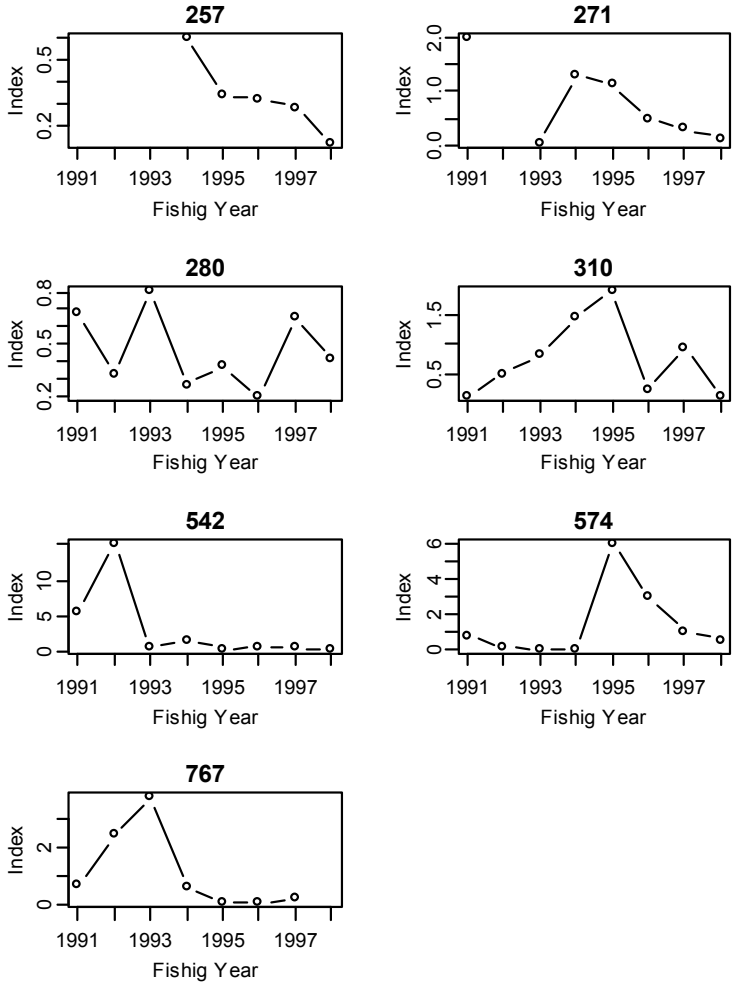

Figure 29: Fishing year index trends for subareas 257, 271, 280, 310, 542, 574, and 767, for the 1990–91 to 1997–98 index with *fishing year* : *subarea* interaction.

When the *fishing year*:*subarea* interaction was not allowed, the normal model instead included the predictor *fishing day*, and explained slightly less of the deviance (20.0% compared to 24.6%, Tables 29 and 31).

Table 31: Predictor and percentage of deviance explained for the final normal model fit for the 1990–91 to 1997–98 index excluding the *fishing year*:*subarea* interaction. Df, degrees of freedom; AIC, Akaike Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained.

Predictor	Step	Df	AIC	%dev.expl	add%dev.expl
Fishing year	1	6	6 178	6.0	6.0
Vessel	2	6	6 029	17.3	11.4
Subarea	3	6	6 016	19.0	1.7
Fishing day	4	3	6 005	20.0	1.0

The residual plots indicated that the models were relatively well fitted compared to the models for fishing years 1998–99 to 2007–08 (Figure 30).

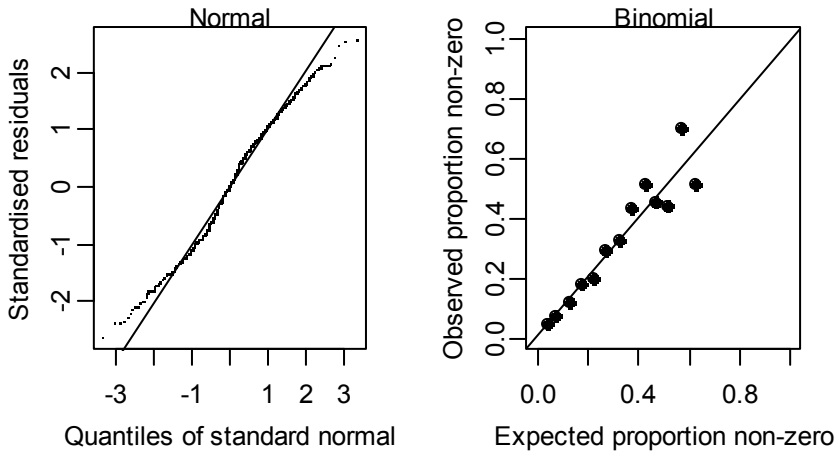

Figure 30: Residuals (left panel) and normal quantile plot (right panel) for the fit for the 1990–91 to 1997–98 index.

The model again showed no difference in success rate between vessels, but a roughly 15-fold difference between the non-zero catch rate (Figure 31).

There was also a substantial difference between the success rate and subsequent catch rate of different subareas, with one area having a much greater chance of success and catch rate (subarea 542, which was on and around Tolaga Knoll). The depth effect indicated greater chance of success in shallower tows, and the fishing day effect greater catch rates in the first three months of the fishing year (October–December), and lowest catch rates around day 250 (June). This would be consistent with lower catch rates when the orange roughy fishery was at a peak (Anderson & Dunn 2008). This suggests that fishing day may be aliasing, to some extent, for a target species effect, and the same may be true for the depth effect.

4.7 Summary of standardised CPUE analyses

The year effects for the four indices are summarised in Table 32. The index for 1990–91 to 1997–98 indicated a decline of at least 50%. The various indices for 1998–99 to 2007–08 indicate a decline of at least another 50%. Despite the differences in the derivation of the indices for 1998–99 to 2007–08, the year trends were similar (Figure 32). The coefficients of variation (c.v.) were estimated using bootstrap resampling, nested by the final categorical predictors, for the combined models, and were reasonably high for all indices. The analytical c.v.s calculated for the non-zero models were similar, and usually slightly lower, than the combined models. The combined models tended to shower a greater decrease over the time series, as the binomial model for fishing success tended to decline after a peak in 2000–01.

For these indices, the standardised CPUE year trends were substantially different from the unstandardised CPUE trends. The standardised trend was therefore clearly dependent upon the model correctly estimating the predictor effects. The data set was dominated by two or three vessels and subareas, and these will have greatest weight in determining the final CPUE year trend. Vessel "11138", for example, became dominant in the fishery only from 2005–06. The degree to which CPUE increased in this year, forming potentially either a smooth continuation from the previous year, or a peak in CPUE, will depend to a large extent on the coefficient estimated for this vessel. The vessels in the analyses for black cardinalfish were different from those used in the orange roughy fishery (Dunn & Anderson 2008), and so

estimated vessel effects could not be compared across fisheries. Clearly, there will be concerns that such coefficients are correctly estimated, especially when the model is used as a biomass index in stock assessment. This will be a particular concern for black cardinalfish in CDL 2, where standardised CPUE is currently the only biomass index available.

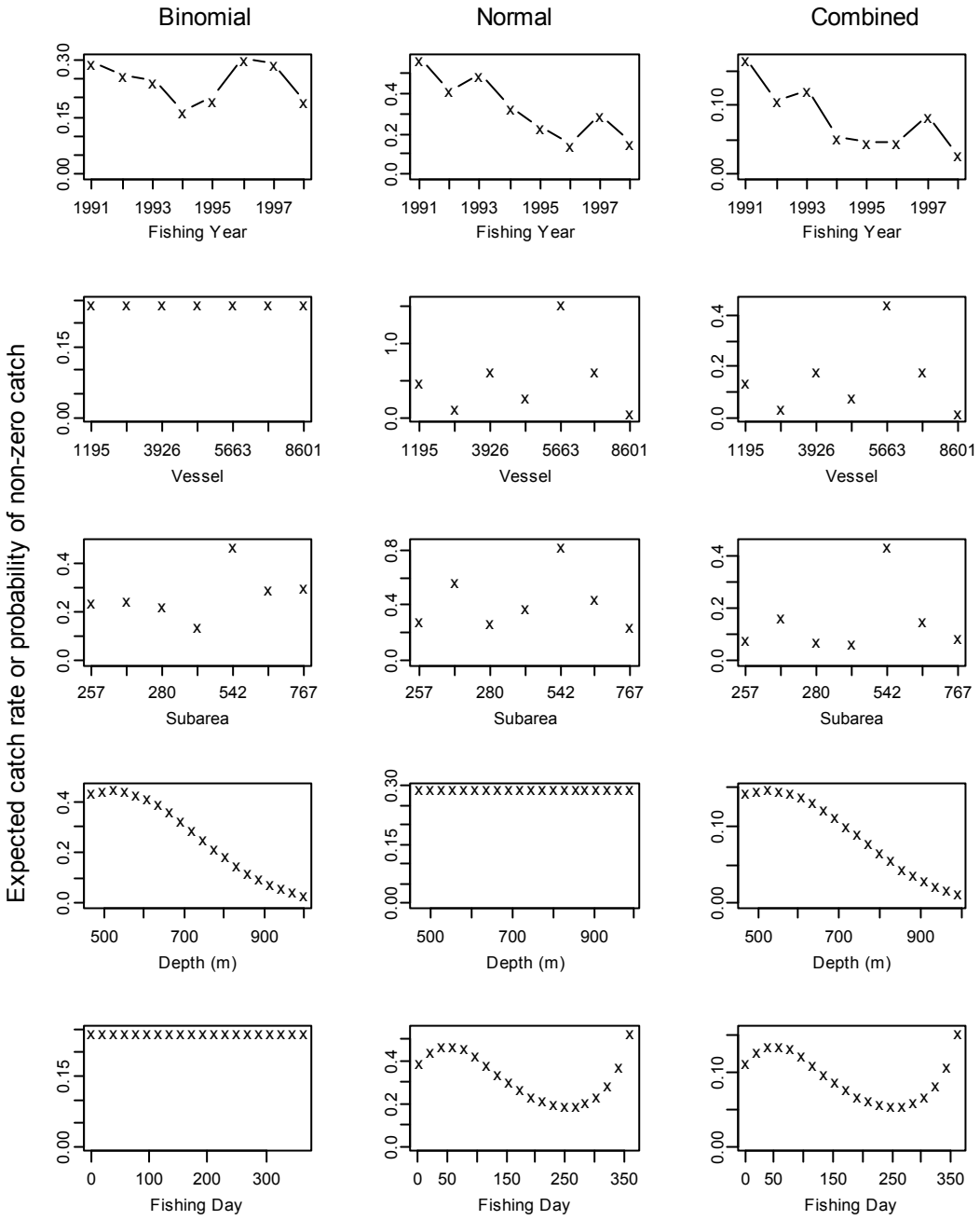

Figure 31: Model predictions for the 1990–91 to 1997–98 index, by *fishing year* (labelled as year ending, i.e., 1991 means 1990–91) v*essel*, subarea, *depth*, and *fishing day*, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values.

Table 32: Year effects and coefficients of variation (c.v.) for the alternative standardised CPUE indices for CDL 2, showing the results of the combined index, and also the non-zero (normal) index.

	1998–99 to 2007–08 *target species*				1998–99 to 2007–08 *target species* no *vessel* "8700"			
	Combined		Non-zero		Combined		Non-zero	
Fishing year	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.
1990–91	–	–	–	–	–	–	–	–
1991–92	–	–	–	–	–	–	–	–
1992–93	–	–	–	–	–	–	–	–
1993–94	–	–	–	–	–	–	–	–
1994–95	–	–	–	–	–	–	–	–
1995–96	–	–	–	–	–	–	–	–
1996–97	–	–	–	–	–	–	–	–
1997–98	–	–	–	–	–	–	–	–
1998–99	1.00	0.57	1.00	0.61	1.00	0.48	1.00	0.37
1999–00	0.88	0.53	0.55	0.57	1.00	0.39	0.57	0.32
2000–01	0.71	0.54	0.38	0.57	0.81	0.42	0.39	0.36
2001–02	0.71	0.52	0.47	0.57	0.82	0.41	0.50	0.35
2002–03	0.49	0.55	0.31	0.57	0.53	0.41	0.30	0.33
2003–04	0.36	0.59	0.28	0.60	0.36	0.46	0.26	0.38
2004–05	0.27	0.59	0.27	0.59	0.23	0.45	0.23	0.35
2005–06	0.46	0.56	0.36	0.59	0.46	0.41	0.34	0.34
2006–07	0.28	0.58	0.28	0.60	0.24	0.43	0.27	0.35
2007–08	0.25	0.60	0.19	0.61	0.23	0.45	0.17	0.37

	1998–99 to 2007–08 no *target species*				1990–91 to 1997–98 no *target species*			
	Combined		Non-zero		Combined		Non-zero	
Fishing year	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.
1990–91	–	–	–	–	1.00	0.46	1.00	0.46
1991–92	–	–	–	–	0.64	0.44	0.73	0.43
1992–93	–	–	–	–	0.73	0.46	0.87	0.42
1993–94	–	–	–	–	0.33	0.48	0.58	0.46
1994–95	–	–	–	–	0.28	0.51	0.41	0.45
1995–96	–	–	–	–	0.27	0.38	0.26	0.39
1996–97	–	–	–	–	0.51	0.45	0.51	0.42
1997–98	–	–	–	–	0.19	0.53	0.29	0.47
1998–99	0.91	0.39	1.00	0.38	–	–	–	–
1999–00	0.58	0.32	0.45	0.31	–	–	–	–
2000–01	0.85	0.33	0.43	0.33	–	–	–	–
2001–02	1.00	0.32	0.58	0.31	–	–	–	–
2002–03	0.64	0.32	0.38	0.31	–	–	–	–
2003–04	0.55	0.40	0.37	0.37	–	–	–	–
2004–05	0.36	0.40	0.34	0.34	–	–	–	–
2005–06	0.52	0.35	0.41	0.33	–	–	–	–
2006–07	0.33	0.36	0.31	0.33	–	–	–	–
2007–08	0.24	0.36	0.20	0.36	–	–	–	–

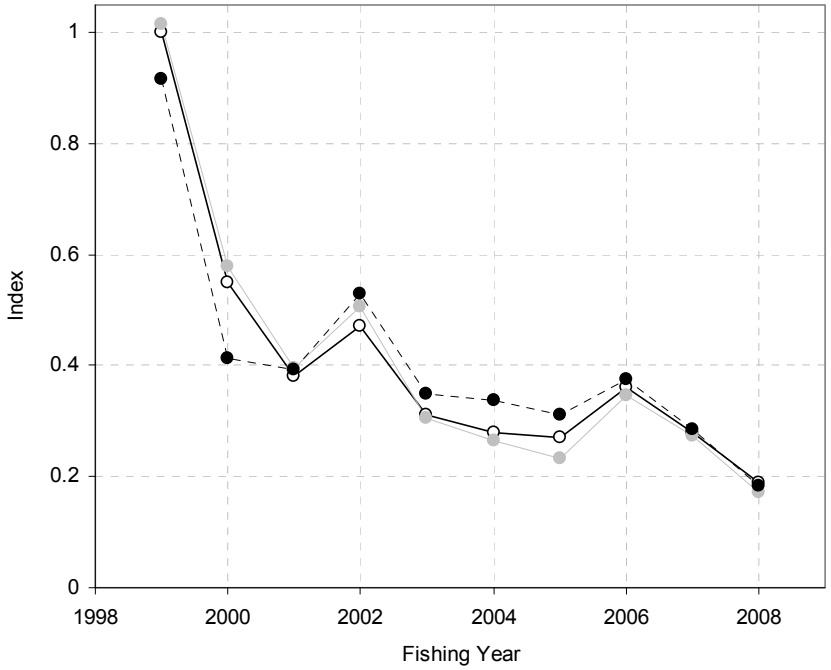

Figure 32: The year index estimated from the non-zero catch (normal) models: 1998–99 to 2007–08 *target species* (solid line and clear points); 1998–99 to 2007–08 no *target species* no *vessel* "8700" (grey line and points); and 1998–99 to 2007–08 no *target species* (solid points and broken line).

5. DISCUSSION

The main fishing areas, as identified by Dunn (2005, 2007), are still yielding catches of black cardinalfish. Reduced catches and catch rates, however, suggest that the black cardinalfish stocks have been fished down.

The explanatory power of the standardised CPUE models was higher than found by Dunn (2007), which is expected given that the indices estimated by Dunn (2007) were for target tows, and specific areas, and so much of the deviance was removed through data selection. The present models accounted for a much higher percentage of the black cardinalfish catch (65–77%) than that of Dunn (2007) (10–32%).

The standardised CPUE was uncertain for black cardinalfish, with relatively high estimated c.v.s. Fishing vessels have moved in and out of the fishery, fishing behaviour appears to have changed over time, and catch reporting behaviour may have changed. Black cardinalfish fishing and catches in some areas seemed unpredictable and erratic, at least compared to other deepwater species such as orange roughy. The relatively high c.v.s therefore seem reasonable, in that they reflect this variability.

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