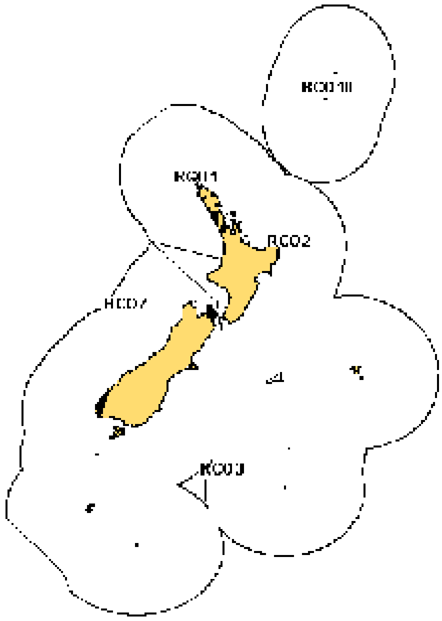
RED COD (RCO)

(*Pseudophycis bachus*)



1. FISHERY SUMMARY

(a) Commercial fisheries

Red cod are targeted primarily by domestic trawlers in the depth range between 30 and 200 m and are also a bycatch of deepwater fisheries off the southeast and southwest coasts of the South Island. The domestic red cod fishery is seasonal, usually beginning in November and continuing to May or June with peak catches around January and May. During spring and summer, red cod are caught inshore before moving into deeper water during winter.

Reported annual catches by nation from 1970 to 1986–87 are given in Table 1. With the introduction of the EEZ and subsequently the QMS, foreign vessel catches declined and were negligible by 1987–88.

Table 1: Reported annual catch (t) of red cod by nation from 1970 to 1986–87.

	New Zealand		Foreign licensed				Grand
Fishing year	**Domestic**	**Chartered**	**Japan**	**Korea**	**USSR**	**Total**	**Total**
1970*	760	–	995	–	–	995	1 755
1971*	393	–	2 140	–	–	2 140	2 533
1972*	301	–	2 082	–	<100	2 182	2 483
1973*	736	–	2 747	–	<100	2 847	3 583
1974*	1 876	–	2 950	–	<100	3 050	4 926
1975*	721	–	2 131	–	<100	2 231	2 952
1976*	948	–	4 001	–	600	4 601	5 549
1977*	2 690	–	8 001	1 358 §	2200	11 559	14 249
1978–79*	5 343	124	2 560	151	51	2 762	8 229
1979–80*	5 638	883	537	259	116	912	7 433
1981–82*	3 210	387	474	70	102	646	4 243
1982–83*	4 342	406	764	675	52	1 493	6 241
1983–83†	3 751	390	149	401	3	553	4 694
1983–84†	10 189	1 764	1 364	480	49	1 893	13 846
1984–85†	14 097	2 381	978	829	7	1 814	18 292
1985–86†	9 035	1 014	739	147	5	891	10 940
1986–87‡	2 620	1 089	197	4	59	261	3 969

1970–1977 = calendar years; 1978–79 to 1982–83 = 1 April–31 March; 1980–1981=no fishing returns processed this year; 1983–1983 – 1 April-30 September; 1983–84 to 1986–87 – 1 October-30 September; * MAF data; † FSU data; ‡ QMS data § mainly ribaldo and red cod.

Recent reported landings and TACs of red cod by Fishstock are shown in Table 2.

Table 2: Reported landings (t) of red cod by Fishstock from 1983–84 to 2003–04 and actual TACCs (t) for 1986–87 to 2004–05.

Fishstock	RCO 1		RCO 2		RCO 3		RCO 7		RCO 10			
FMA (s)	1 & 9		2 & 8		3, 4, 5 & 6		7		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings§	TACC
1983–84*	12	–	197	–	9 357	–	3 051	–	0	–	13 848	–
1984–85*	9	–	126	–	14 751	–	1 442	–	0	–	18 292	–
1985–86*	6	–	48	–	9 346	–	408	–	0	–	10 940	–
1986–87†	5	30	46	350	3 300	11 960	619	2 940	0	10	3 970	15 290
1987–88†	8	40	81	357	2 878	12 182	1 605	2 982	0	10	4 506	15 571
1988–89†	9	40	85	359	7 732	12 362	1 345	3 057	0	10	9 171	15 828
1989–90†	8	42	105	362	6 589	13 018	800	3 105	0	10	7 502	16 537
1990–91†	12	42	68	364	4 630	12 299	839	3 125	0	10	5 549	15 840
1991–92†	26	42	358	364	6 500	12 299	2 220	3 125	0	10	9 104	15 840
1992–93†	46	42	441	364	9 633	12 389	4 083	3 125	0	10	14 203	15 930
1993–94†	44	42	477	364	7 977	12 389	2 992	3 125	0	10	11 491	15 930
1994–95†	63	42	762	364	12 603	12 389	3 569	3 125	0	10	16 997	15 930
1995–96†	28	42	584	500	11 038	12 389	3 728	3 125	0	10	15 350	16 066
1996–97†	42	42	396	500	10 056	12 389	3 710	3 125	0	10	14 204	16 066
1997–98†	22	42	192	500	9 972	12 389	2 700	3 125	0	10	12 886	16 066
1998–99†	10	42	282	500	13 926	12 389	2 055	3 125	0	10	16 273	16 066
1999–00†	3	42	130	500	4 824	12 389	633	3 125	0	10	5 590	16 066
2000–01†	5	42	112	500	2 776	12 389	1 538	3 125	0	10	4 432	16 066
2001–02†	6	42	150	500	2 862	12 389	1 409	3 125	0	10	4 427	16 066
2002–03†	8	42	144	500	5 107	12 389	1 657	3 125	0	10	6 916	16 066
2003–04†	11	42	225	500	7 724	12 389	2 358	3 125	0	10	10 318	16 066
2004–05†	20	42	423	500	4 211	12 389	3 033	3 125	0	10	7 687	16 066

* FSU data.
† QMS data.
§ Includes landings from unknown areas before 1986–87.

Since 1983–84, the bulk of the reported landings have been taken from RCO 3, in particular the Canterbury Bight and Banks Peninsula areas. The red cod fishery is characterised by large variations in catches between years. Current research indicates that these variations in catches are due to fluctuations in biomass as recruitment varies, rather than changes in catchability. Annual landings have been substantially lower than the TACCs in all QMAs since 1999-00 and, with the exception of the 2003-04 fishing year, total catches have been below 10,000 t.

(b) Recreational fisheries

Recreational fishers take red cod, particularly on the east coast of the South Island. Results of five separate recreational fishing surveys are shown in Table 3.

Table 3: Estimated number and weight of red cod harvested by recreational fishers by Fishstock and survey. Surveys were carried out in different years in the Ministry of Fisheries regions: South in 1991–92, Central in 1992–93, North in 1993–94 (Teirney et al., 1997) and Nationally in 1996 (Bradford, 1998) and 1999-00 (Boyd & Reilly, 2002). Survey harvest is presented as a range to reflect the uncertainty in the estimates.

Fishstock	Survey	Number	*c. v.%*	Estimated harvest range (t)	Estimated point estimate (t)
1991-92					
RCO 3	South	104 000	16	90-120	-
RCO 7	South	1 000	-	0-5	-
1992-93					
RCO 2	Central	151 000	19	105-155	-
RCO 7	Central	11 00	34	5-15	-
1993-94					
RCO 1	North	9 000	34	5-15	-
1996					
RCO 1	National	11 000	18	5-15	11
RCO 2	National	88 000	11	80-105	92
RCO 3	National	99 000	10	90-115	103
RCO 7	National	38 000	15	30-50	40
1999-00					
RCO 1	National	21 000	35	5-11	-
RCO 2	National	39 000	25	8-14	-
RCO 3	National	207 000	25	210-349	-
RCO 7	National	23 000	50	5-14	-

A key component of the estimating recreational harvest from diary surveys is determining the proportion of the population that fish. The Recreational Working Group has concluded that the methodological framework used for telephone interviews produced incorrect eligibility figures for the 1996 and previous surveys. Consequently the harvest estimates derived from these surveys are considered to be considerably underestimated and not reliable. However relative comparisons can be made between stocks within these surveys. The Recreational Working Group considered that the 2000 survey using face-to-face interviews better estimated eligibility and that the derived recreational harvest estimates are believed to be more accurate. FMA2 catches are nevertheless considered to be over-estimate, probably because of an unrepresentative diarist sample. The 1999/2000 Harvest estimates for each Fishstock should be evaluated with reference to the coefficient of variation.

(c) Maori customary fisheries

Quantitative estimates of the current level of Maori customary take are not available.

(d) Illegal catch

Quantitative estimates of the level of illegal catch are not available.

(e) Other sources of mortality

Processing limits on red cod are sometimes imposed to discourage fishers from landing red cod when the species cannot be processed or when markets are poor. This practice has encouraged dumping. Processing limits are currently less of a problem than in earlier years.

2. BIOLOGY

Red cod are a fast-growing, short-lived species with few fish in the commercial fishery older than six years. Red cod grow to about 25 cm total length (TL) in the first year, followed by annual growth increments of around 15, 10 and 5 cm. Growth of sexes is similar for the first two years, after which females tend to grow faster than males and reach a larger overall length. Sexual maturity ranges from 45 to 55 cm TL with a mean value of 52 cm TL for both sexes at an age of 2–3 years. M has been estimated to equal 0.76 for both sexes. In 1995, ageing of red cod was validated.

In the 1989–90 to 1992–93 fishing years, 80% of the landings in RCO 3 were 2^+ and 3^+ fish (50–57 cm TL). The sex ratio of the commercial catch during this period was skewed towards females during November (ratio F:M of 3.4:1) with the ratio tending to even out by May. Schools are generally comprised of single age cohorts rather than a mix of age classes.

Spawning in red cod varies with latitude, with spawning occurring later at higher latitudes. In the Canterbury Bight, spawning occurs from August to October. No definite spawning grounds have been identified on the southeast coast, but there is some evidence that red cod spawn in deeper water (>300–750 m). Running ripe fish were caught on the Puysegur Bank in 600 m during the Southland trawl survey in February 1994. Juvenile red cod are found in offshore waters after the spawning period; however, no nursery grounds are known for this species.

Red cod are seasonally abundant, with schools appearing in the Canterbury Bight and Banks Peninsula area around November. These schools are feeding aggregations and are not found in these waters after about June. Catch data indicates that they move into deeper water after this time. Recruitment is highly variable resulting in large variations in catches between years.

Biological parameters relevant to the stock assessment are shown in Table 4.

Table 4: Estimates of biological parameters for red cod.

Fishstock	Estimate						Source
1. Natural mortality (M)							
RCO 3	0.76						Beentjes (1992)
2. Weight = a (length)^b (Weight in g, length in cm fork length)							
	Females			**Males**			
RCO 3	a = 0.0074	b = 3.059		a = 0.0145	b = 2.892		Beentjes (1992)
3. von Bertalanffy growth parameters							
	Females			**Males**			
	K	**t_0**	**L_∞**	**K**	**t_0**	**L_∞**	
RCO 3	0.41	–0.03	76.5	0.47	0.06	68.5	Horn (1995)
RCO 7	0.49	0.20	79.6	0.53	0.22	68.2	Beentjes (2000)

3. STOCKS AND AREAS

The number of red cod stocks is unknown. There are no new data which would alter the stock boundaries given in previous assessment documents.

4. STOCK ASSESSMENT

This is the first stock assessment carried out for red cod.

(RCO 3) South-East, Southland, Chatham Islands & Sub-Antarctic, and (RCO 7) Challenger

A stock reduction analysis was carried out for RCO 3 and RCO 7 stocks in 1999 using the MIAEL estimation technique (Cordue 1998a,b). Estimates were made for mid spawning season virgin biomass (B_0), mid spawning season current biomass (1998–99, B_{mid99}/B_0), beginning of season home ground total biomass (1999–2000, B_{beg00}) and mid spawning season current biomass for next year (B_{mid00}/B_0). MCY and CAY were also determined.

The estimation method had a two-step approach. The first step was a multi-parameter estimation in which unknown parameters, relative year class strength, B_0, home ground selectivity and trawl selectivity were estimated using the single stock least squares model (Cordue 1998a). In the second step, these parameters were fixed at their estimated least squares values, except B_0, and then used in the MIAEL estimation technique (Cordue 1998b) in a single parameter estimation of B_0 and performance index (a measure of the reliability with which the estimate is determined within its known range).

(a) Estimation of fishery parameters and abundance

Estimates of fishery parameters are given in Table 5. Note that Z is likely to be greater than the estimates below based on ageing validation in 1995 (Horn 1995).

Table 5: Estimates of fishery parameters.

Fishstock	Estimate		Source
1. Total mortality (Z)			
	Females	**Males**	
RCO 3–1990	1.67	1.56	Beentjes (1992)
RCO 3–1991	1.64	1.42	Beentjes (1992)

Catch histories used in the model are shown in Table 6 and other model input parameters are given in Table 8. For both stocks all fishing was assumed to take place on the home ground with no spawning season catch; spawning length was entered as 0 in the basecase model. A sensitivity analysis was carried out assuming a spawning length of 0.1 and catches were partitioned between home ground (83.4%) and spawning ground (16.6%). These proportions were generated by dividing the total annual catch by 12 months and the catch for the spawning period was taken as the catch for two of the 12 months. There are no catch records available from 1960 to 1970 and therefore catch for this period was estimated and set at about the mean annual catch for the 1970s (RCO 3, 3000 t, RCO 7, 600 t). Catches for 1999 were estimated close to end of the fishing year and are close to the actual landings; 2000 catches were assumed to be at the level of the mean catch for the 1990s.

RCO 3 relative abundance indices

Data from five east coast South Island (ECSI) winter trawl surveys and the first three ECSI summer trawl surveys were input into step one of the model as numbers at age and sex of 1+ and 2+ fish (winter), and numbers at age and sex of 0+, 1+, 2+ and 3+& older fish (summer). The model does not cater for 0+ age groups and therefore to include the 0+ fish they were entered as 1+ fish the following year. Model c.v.s for numbers at age were obtained by weighting a median c.v. of 25 by the number of tows. Total biomass estimates from both summer and winter surveys were used in the second step of the MIAEL estimation procedure (Table 8) and c.v.s for biomass were obtained by weighting a median c.v. of 25 (summer) and 35 (winter) by the number of tows.

Data from east coast South Island red cod catch sampling programme (1990–93) were input into step one of the model as proportion at age and sex of 1+, 2+, 3+ and 4+ fish. Model c.v.s for each year were obtained by weighting a median c.v. of 25 by the number of samples.

Relative year effects from standardised CPUE analyses for the period 1989–90 to 1997–98 (CELR and TCEPR) were input into step one and two of the model as mature biomass and a median c.v. of 35% was applied to each years CPUE data (Table 9). Red cod was used as the target species for CELR and TCEPR analyses.

An environmental abundance index determined from the relationship between environmental variables and actual commercial catch in RCO 3 for the fishing years 1970–71 to 1997–98 was input into step one and two as biomass. Variables most strongly correlated with commercial catch were used to predict abundance for input into the MIAEL model sensitivity analysis. The predictors SST and Trough NW cluster, with a 14 month lag, explained 68% of variability in commercial catch. A median c.v. of 35% was applied to each yearly abundance estimate.

RCO 7 relative abundance indices

Data from west coast South Island trawl surveys were input into the model as numbers at age and sex of 0+, 1+ and 2+ & older fish, determined from MIX analysis. As for RCO 3, 0+ fish were entered as 1+ fish the following year. Model c.v.s for numbers at age were obtained by weighting a median c.v. of 25 by the number of tows. Total biomass estimates from these surveys were used in the MIAEL estimation procedure (Table 8). Model c.v.s for biomass were obtained by weighting a median c.v. of 25 by the number of tows.

Relative year effects from standardised CPUE analyses for the period 1989–90 to 1997–98 (CELR only) were input into step one and two of the model as mature biomass and a median c.v. of 35% was applied to each years CPUE data (Table 9). TCEPR data was not included because it was considered that this index was not a good indicator of red cod abundance. Red cod, flatfish and barracouta were used as target species.

An environmental abundance index determined from the relationship between environmental variables and actual commercial catch in RCO 7 for the fishing years 1970–71 to 1997–98 were input into step one and two as biomass as per RCO 3. Variables most strongly correlated with commercial catch were used to predict abundance for input into the MIAEL model sensitivity analysis. The predictors SST and surface westerly wind, with a 14 month lag, explained 75% of variability in commercial catch. A median c.v. of 35% was assigned to each yearly catch estimate.

Table 6: Catch history of home ground catches for RCO 3 and RCO 7.

Year	RCO 3	RCO 7	Year	RCO 3	RCO 7
1960	3 000	600	1981	3 219	696
1961	3 000	600	1982	3 854	1 220
1962	3 000	600	1983	6 305	1 514
1963	3 000	600	1984	9 357	3 051
1964	3 000	600	1985	14 751	1 442
1965	3 000	600	1986	9 346	408
1966	3 000	600	1987	3 300	619
1967	3 000	600	1988	2 878	1 605
1968	3 000	600	1989	7 732	1 345
1969	3 000	600	1990	6 589	800
1970	3 000	600	1991	4 630	839
1971	1 815	534	1992	6 500	2 220
1972	1 890	548	1993	9 633	4 083
1973	2 567	755	1994	7 977	2 992
1974	3 553	1 043	1995	12 603	3 569
1975	2 508	711	1996	11 038	3 728
1976	3 854	1 142	1997	10 042	3 694
1977	9 619	2 869	1998	9 954	2 621
1978	7 610	2 779	1999*	14 000	2 052
1979	5 987	1 698	2000*	9 297	2 637
1980	5 637	1 637			

Table 7: Base case and sensitivity input parameters for RCO 3 and RCO 7.

Parameter	Base case	Sensitivities
Environmental abundance index		included
CPUE data weighting	0.5	1
Age data weighting	1	
Proportion of year spawning	0	0.1
r_{hm_max} (Max exploitation)	0.7	0.8, 0.5
r_{hm_mmax} (minimum catch when highest exploitation)	0.05	0.02
pspawn (Proportion of mature fish that spawn)	1	
mlow (Lowest maturity age)	1	
mhigh (High age at which there are immature fish)	4	3
M (males, females) Mortality	0.75, 0.7	0.9, 0.85, and 0.65, 0.6
Steepness (SSR)	0.75	
Maturity ogive	0.1, 0.2, 0.9, 1.0	
Home ground selectivity ogive (RCO 3/ RCO 7)	estimated/fixed	
Trawl selectivity	estimated	
Ageing error	± 10%	

Trawl survey biomass estimates are available from one *Tangaroa* and four *Kaharoa* time series (Table 8). In 2001, the Inshore FAWG recommended that the east coast South Island trawl survey be discontinued due to the extreme variability in the catchability of the target species.

Table 8: Biomass indices (t) and coefficients of variation (*c.v.*) –, no data. Vertical and areal availability and vulnerability were assumed to equal 1.0. Pre-recruit biomass are red cod < 41 cm.

Fishstock	Area	Trip code	Date	Biomass	% c.v.	Pre-recruit biomass	% c.v.
RCO 2	East coast	KAH 9304	Feb-Mar 1993	913	52	197	31
	North Island	KAH 9402	Feb-Mar 1994	1 298	50	547	52
		KAH 9502	Feb-Mar 1995	469	36	47	34
RCO 3	East coast	KAH 9105	May-Jun 1991	3 545	33	1 787	44
	South Island	KAH 9205	May-Jun 1992	4 527	40	2 277	50
	(Winter)	KAH 9306	May-Jun 1993	5 601	29	1 252	50
		KAH 9406	May-Jun 1994	5 803	31	3 625	37
		KAH 9606	May-Jun 1996	4 567	30	664	31
RCO 3	Southland	TAN 9301	Feb-Mar 1993	100	68	–	–
		TAN 9402	Feb-Mar 1994	707	68	–	–
		TAN 9502	Feb-Mar 1995	2 554	49	182	66
		TAN 9604	Feb-Mar 1996	33 390	94	736	99

Table 8: (*continued*)

Fishstock	Area	Trip code	Date	Biomass	% c.v.	Pre-recruit biomass	% c.v.
RCO 7	West coast	KAH 9204	Mar-Apr 1992	2 719	13	1 167	17
	South Island	KAH 9404	Mar-Apr 1994	3 169	18	888	25
		KAH 9504	Mar-Apr 1995	3 123	15	1 007	18
		KAH 9701	Mar-Apr 1997	2 546	23	1 353	28
		KAH 0004	Mar-Apr 2000	414	26	–	–
		KAH 0304	Mar-Apr 2003	906	24	290	31
RCO 3	East coast	KAH 9618	Dec-Jan 1996–97	10 634	23	4 101	23
	South Island	KAH 9704	Dec-Jan 1997–98	7 536	23	4 426	24
	(Summer)	KAH 9809	Dec-Jan 1998–99	12 823	17	3 770	15
		KAH 9917	Dec-Jan 1999–00	6 690	30	2728	41
		KAH 0014	Dec-Jan 2000–01	1 402	82	1 283	89

Table 9: Standardised catch per unit effort indices for RCO 3 and RCO 7. s.e., standard error.

				RCO 3		RCO 7
		CELR		TCEPR		CELR
Year	Year effect	s.e.	Year effect	s.e.	Year effect	s.e.
1989–90	1	0	1	0	1	0
1990–91	0.7336	0.0324	0.7262	0.0667	0.9031	0.0349
1991–92	0.7487	0.0305	0.9488	0.0651	1.7317	0.0618
1992–93	0.8146	0.0322	1.2372	0.0810	2.4287	0.0794
1993–94	0.9122	0.0352	1.2736	0.0889	2.9812	0.1015
1994–95	1.2209	0.0456	1.6295	0.1188	2.7135	0.0897
1995–96	1.1612	0.0457	1.3929	0.0909	3.0518	0.1021
1996–97	0.8502	0.0328	1.0256	0.0702	3.0271	0.1003
1997–98	0.6526	0.0256	1.0149	0.0709	2.5362	0.0880

Year class strengths

Year class strengths were estimated for the years 1986 to 1998 (RCO 3) and 1989 to 1996 (RCO 7) (Table 10). These periods were defined by available input data that included information on age classes. In both stocks the environmental abundance index was used as a sensitivity analysis. Home ground fishing selectivity ogives (RCO 3 only) and trawl survey selectivity ogives were also estimated with a fixed maturity ogive (Tables 11 & 12). Home ground selectivity was fixed for RCO 7 using proportions similar to RCO 3 rather than being estimated at each run because there was no fishing data to estimate this ogive. For missing age classes (3+ and 4+ fish) in the east coast South Island winter trawl surveys, age selectivities were assumed by the model to be the same as 2+ fish. Similarly for the summer surveys, the 4+ selectivities were assumed by the model to be the same as 3+ fish and for the west coast surveys, 3+ and 4+ selectivities were assumed by the model to be the same as 2+ fish. Initial estimates of YCS were considered to be too high and were encouraged to average about 1. For sensitivity analyses, selected parameters were changed and YCS re-estimated. Once determined, these parameters were then used to obtain estimates of B_{min} and B_{max}, which are the lowest and highest values of virgin biomass that are consistent with the catch history.

Table 10: Estimated year class strengths (YCS) for base case and sensitivity 1 for RCO3 and RCO 7, rsd = recruitment variability.

Year	RCO 3 basecase	RCO 3 sens 1	RCO 7 basecase	RCO 7 sens 1
1986	0.01	0.01	–	–
1987	1.06	2.92	–	–
1988	0.50	0.32	–	–
1989	1.36	1.13	0.01	0.01
1990	3.27	3.33	3.17	3.50
1991	1.43	1.00	0.08	0.13
1992	2.56	2.81	3.15	4.11
1993	2.16	1.39	0.01	0.02
1994	0.89	0.66	0.23	0.38
1995	1.40	0.45	2.62	2.43
1996	1.80	0.65	0.23	0.31
1997	0.59	0.19	–	–
1998	0.38	0.14	–	–
Mean YCS	1.34	1.15	1.19	1.36
Rsd	1.47	1.6	2.4	2.35

Table 11: Home ground selectivities for RCO 3 basecase (estimated for all runs) and RCO 7 (fixed for base case and all sensitivities).

	RCO 3		RCO 7	
		basecase		all runs
Age	male	female	male	female
1	0.01	0.01	0.1	0.1
2	1.5	1.5	0.8	0.8
3	1.5	1.5	1.0	1.0
4	1.0	0.8	1.0	1.0

Table 12: Base case estimates of trawl survey vulnerabilities for east and west coast South Island trawl surveys. *different proportionality constants were used for 0+ and 1+ fish.

East coast South Island winter trawl surveys

Age	Males	Females	Comments
1	0.59	0.45	
2	1.00	1.20	
3	1.00	1.20	assumed by model to be the same as 2 yr olds
4	1.00	1.20	assumed by model to be the same as 2 yr olds

East coast South Island summer trawl surveys

Age	Males	Females	Comments
0	8.93	6.68	input in the model as 1 year olds
1	8.93	6.68	
2	6.18	8.06	
3	1.00	1.20	
4	1.00	1.20	assumed by model to be the same as 3 yr olds

Standardized to males age 2

Age	Males	Females
0	–	–
1	1.44	1.08
2	1.00	1.30
3	0.16	0.19
4	–	–

West coast South Island autumn trawl surveys

Age	Males	Females	Comments
0	0.19	0.22	input in the model as 1 year olds
1	0.19	0.22	
2	1.00	0.62	
3	1.00	0.62	assumed by model to be the same as 2 yr olds
4	1.00	0.62	assumed by model to be the same as 2 yr olds

b) Biomass estimates

RCO 3 and RCO 7 estimates and ranges for mid spawning season virgin biomass (B_0), mid spawning season current biomass (1998–99, B_{mid99}/B_0), beginning of season home ground total biomass (1999–00, B_{beg00}) and mid spawning season current biomass for next year (B_{mid00}/B_0) are shown in Tables 13 and 14. RCO 3 and RCO 7 least squares estimates of all biomass estimates were the same as B_{max} in all runs. This may be caused by the flat nature of the trawl survey biomass estimates which results in the best fit at maximum B_0.

RCO 3

The MIAEL estimate of virgin biomass was 58 000 t and current biomass (B_{mid99} and B_{mid00}) ranged from 25–135% of B_0 (performance index, 15%) and 14–126% of B_0 (performance index, 15%), respectively. In general the estimates of virgin biomass, current biomass and beginning of season biomass have wide ranges and the performance indices are low, indicating that the point estimates are not well estimated within their known range of values. The sensitivity analysis including environmental abundance results in the lowest estimates of B_{mid99} and B_{mid00}.

RCO 3 Biomass trajectories for B_{min} and B_{max} and current and estimates of B_{mid99} and B_{mid00} for the base case are given in Figure 1.

Table 13: RCO 3 least squares (LS) estimates of biomass and bounds (B_{min} and B_{max}), and MIAEL estimates of biomass with performance indices (PI).

Estimate	Run	Bmin	Bmax	LS	MIAEL	PI (%)
B0	**Base**	**19 500**	**107 500**	**107 500**	**58 000**	**17**
	sens 1 environ	22 805	143 271	143 271	84 500	32
Bmid99 (%B0)	**Base**	**25**	**135**	**135**	**75**	**15**
	sens 1 environ	4	74	74	47	50
Bbeg00	**Base**	**22 279**	**322 120**	**322 120**	**118 000**	**15**
	sens 1 environ	3 924	186 052	186 052	87 000	43
Bmid00 (%B0)	**Base**	**14**	**126**	**126**	**49**	**6**
	sens 1 environ	1	55	55	12	15

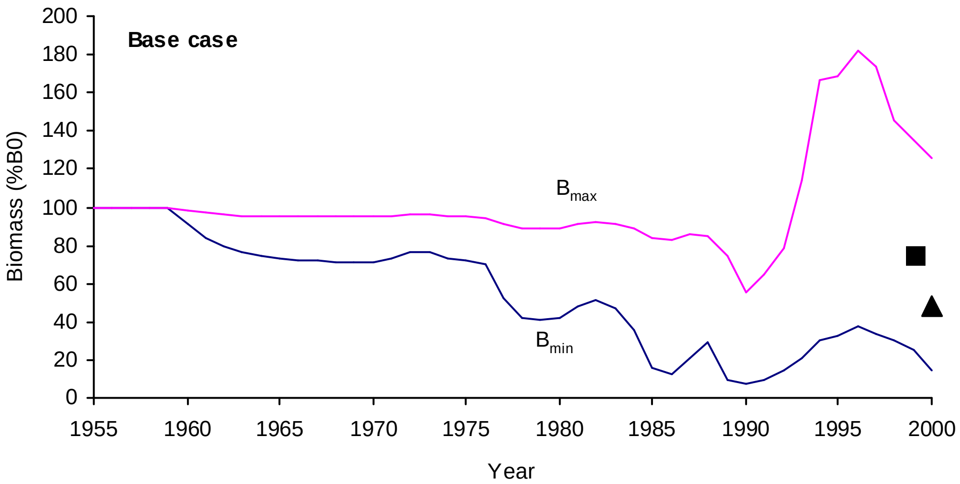


Figure 1: RCO 3 biomass trajectory for B_{min} and B_{max} for the basecase. Square, B_{mid99}; triangle B_{mid00}.

RCO 7

The MIAEL estimate of virgin biomass was 20 000 t and current biomass (B_{mid99} and B_{mid00}) ranged from 1–111% of B_0 (performance index, 32%) and 1–85% of B_0 (performance index, 49%), respectively. In general the estimates of virgin biomass, current biomass and beginning of season biomass have wide ranges and the performance indices range from low to high, indicating that the point estimates are well estimated within their known range of values for some runs and poorly estimated for others. The higher performance indices of RCO 7 compared to RCO 3 is partly due to the difference in biomass. At low biomasses, relative indices are more informative than at high biomasses because the catch history causes a relatively larger decline and relative abundance indices are more likely to track biomass. Unlike RCO 3, the sensitivity analysis including environmental abundance results in higher estimates of B_{mid99} and B_{mid00} than the basecase.

For RCO 7 the most recent YCS estimated was for 1996 and these fish are no longer in the fishery. The YCSs estimated since 1996 are therefore based on the assumption of mean recruitment for each year and the estimates of B_{mid99} and B_{mid00} are probably driven by the CELR CPUE index and the recent high landings.

RCO 7 Biomass trajectories for B_{min} and B_{max} and current and estimates of B_{mid99} and B_{mid00} for the base case are given in Figure 2.

Table 14: RCO 7 least squares (LS) estimates of biomass and bounds (B_{min} and B_{max}), and MIAEL estimates of biomass with performance indices (PI).

Esimate	Run	Bmin	Bmax	LS	MIAEL	PI (%)
B0	**Base**	**4 895**	**26 887**	**26 887**	**20 000**	**55**
	Sens 1 environ	4 450	22 212	22 212	17 000	59
Bmid99 (%B0)	**Base**	**1**	**111**	**111**	**49**	**32**
	Sens 1 environ	2	113	113	92	92
Bbeg00	**Base**	**2 125**	**74 691**	**74 691**	**57 500**	**75**
	Sens 1 environ	3 017	63 281	63 281	49 500	76
Bmid00 (%B0)	**Base**	**1**	**85**	**85**	**51**	**49**
	Sens 1 environ	1	87	87	84	93

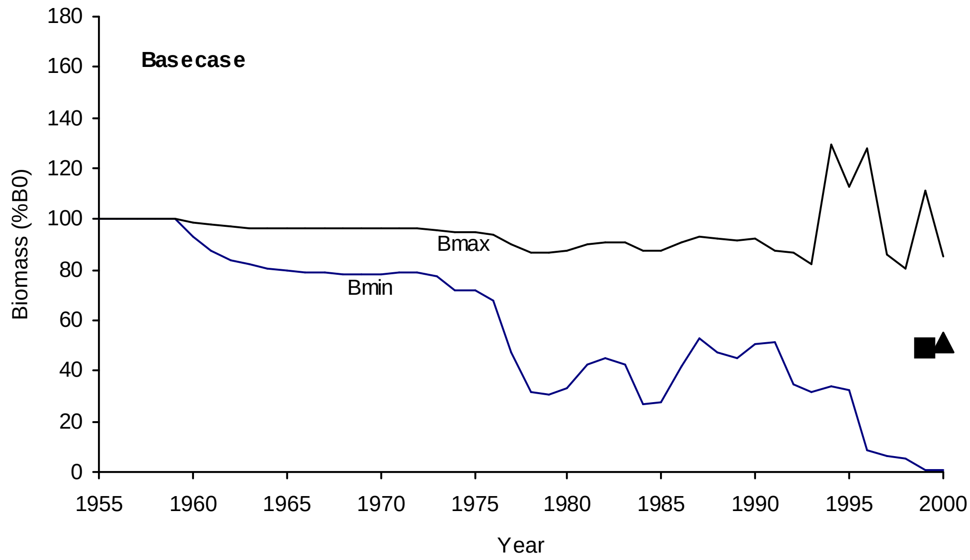


Figure 2: RCO 7 biomass trajectory for B_{min} and B_{max} for the basecase. Square, B_{mid99}; triangle B_{mid00}.

(c) Estimation of Maximum Constant Yield (MCY)

Two methods were used to estimate MCY

1. MCY was estimated for all stocks using the equation MCY = cY_{av} (Method 4, Annala et al., 1998). For all Fishstocks the average of the 1983–84 to 1990–91 domestic and foreign commercial catches has been used, assuming relatively constant effort. Catches from unknown areas before 1986 have been attributed to RCO 3 and RCO 7 using a 6:1 ratio (the average of the ratio of the reported catches over this time).

The practice of discarding red cod has probably resulted in a conservative estimate of MCY since more fish are caught than are landed.

2. MCY was estimated for RCO 3 and RCO 7 by the method MCY = $p.B_0$, where p is determined using the method of Francis (1992) such that biomass does not fall below 20% of B_0 more than 10% of the time. B_0 is estimated by the MIAEL method of Cordue (1998b). Recruitment variability (rsd) used to determine MCY was 1.0.

(i) Auckland and Central (RCO 1 and RCO 2)

MCY = 0.6 * 103 t = 61.8 t (rounded to 60 t).

(ii) South-East, Southland, Chatham Islands & Sub-Antarctic (RCO 3)

Method 1 (MCY=cYav)

MCY = 0.6 * 7322 t = 4393 t (rounded to 4400 t).

Method 2 (MIAEL method)

Estimates of MCY and associated equilibrium biomass are presented in Table 16.

(iii) Challenger (RCO 7)

Method 1 (MCY=cYav)

MCY = 0.6 * 1340 t = 804 t (rounded to 800 t).

For Method 1, the level of risk to the stock by harvesting the population at the estimated MCY has not been estimated.

Method 2 (MIAEL method)

Estimates of MCY and associated equilibrium biomass are presented in Table 15.

Table 15: RCO 3 and RCO 7 model estimates of B_{MCY} and MCY (as a percentage of B_0), MCY and performance indices from the MIAEL estimation.

Fishstock	Run	B_{MCY} (%B_0)	MCY (%B_0)	MCY (t)	MCY Range	PI %
RCO 3	Base case	71.3	12.4	7 173	2 418–13 330	17
RCO 7	Base case	71.6	12.8	2 568	628–3 452	55

(d) Estimation of Current Annual Yield (CAY)

The method of Francis (1992) was used to estimate the range and point estimates of CAY from the range (B_{min} and B_{max}) and point estimates (MIAEL) of (B_{beg00}) (Table 16). Recruitment variability (rsd) used to determine CAY was 1.0.

Table 16: RCO 3 and RCO 7 model estimates of B_{MAY} and MAY (as a percentage of B_0), CAY and performance indices from the MIAEL estimation.

Fishstock	Run	B_{MAY} (% B0)	MAY (% B0)	CAY (t)	Range	PI (%)
RCO 3	base case	47.4	24.1	14 561	2 624–37 976	15
RCO 7	base case	46.4	25.9	7 084	260–9 188	75

(e) Other factors

There have been large fluctuations in red cod abundance and landings, particularly on the east and west coast of the South Island. This causes problems for the fishers who rely on red cod, and creates additional pressure on the bycatch trade-off system. Changes in catch rates of red cod, combined with the recovery of other quota species since the introduction of the QMS, has resulted in a catch mix for which some fishers do not have the appropriate quota holdings. Bycatch problems while targeting red cod are therefore common for stargazer, red gurnard, elephant fish, rig, school shark, blue cod, groper and tarakihi. As a result, effort into targeting red cod may be reduced to alleviate bycatch problems, despite the availability of red cod quota.

5. STATUS OF THE STOCKS

Yearly fluctuations in the red cod catch reflect changes in abundance as recruitment varies. Trawl surveys and catch sampling of red cod have shown that the fishery is based almost exclusively on two and three year old fish and is highly dependent on recruitment success.

The disparity between the TACC and reported landings indicates that the TACC is not generally attainable. The rationale for introducing and retaining a TACC of this magnitude was to provide the fishing industry with the flexibility to capitalise on years when red cod are plentiful. TACCs were exceeded in 1994–95 and 1998–99, when total catches were the highest since the introduction of the QMS. However, since then total landings have declined and recent catches in the major Fishstocks have been lower than the Yav and MIAEL method MCY estimates.

RCO 1 & RCO 2

For RCO 1 and RCO 2 it is not known if the current TACCs and recent catch levels are sustainable or if they are at levels that will allow the stocks to move towards a size that will support the MSY.

RCO 3

The stock assessment model was based on data up to the end of the 1997–98 fishing year. The assessment results indicated that the mid spawning season biomass for B_{mid99} was about 75% of B_0 (range 25–135%, performance index 15%); and for B_{mid00} was about 49% of B_0 (range 14–126%, performance index 6%). Current biomass appears to be greater than stock size that will support the B_{MSY}. The stock assessment of RCO 3 is uncertain as estimates from sensitivity analyses vary widely and performance indices are generally very low (all < 50%) indicating that the point estimates of biomass are not well estimated within their known range. Additionally, the biomass estimates using the least squares estimator are at the assumed upper bound.

The mid 1990's saw the most sustained period of consistently high annual landings in the RCO 3 fishery since catch records began, indicating that recruitment was strong prior to and during this period. YCS estimates could only be made as far back as 1986 but indicate that recruitment was stronger in the 1990s compared to the late 1980s. The weak level of recruitment estimated in 1997 and 1998 indicated that poor catches could be expected in 1999–00 and 2000–01. Consequently, landings in RCO 3 were low in 1999–00 and 2000–01 (4824 t and 2776 t respectively), less than half that of landings of previous years.

For RCO 3 a constant catch at the level of the current TACC is unlikely to be attainable or sustainable in most years.

An analysis of recruitment–environment relationship showed that in RCO 3 there is a strong correlation between recruitment and environmental variables with a periodic 14 month time lag. The stock assessment model was sensitive to inclusion of the environment abundance index which predicts a sharp decline in recruitment in recent years. However the predictive power of the environment–abundance model in RCO 3 proved to be poor for the most recent years (i.e., YCS estimates low and landings high).

RCO 7

The stock assessment model was based on data up to the end of the 1997–98 fishing year. The assessment results indicated that the mid spawning season biomass for B_{mid99} was about 49% of B_0 (range 1–111%, performance index 32%); and about 51% of B_0 for B_{mid00} (range 1–85%, performance index 49%). Current biomass appears to be greater than stock size that will support the B_{MSY}. Although point estimates of biomass were, in some cases, well estimated within their known range, the stock assessment of RCO 7 is also uncertain. Sensitivity analyses have a wide range and least squares biomass estimates were at the upper bound in all cases. Also, the most recent YCS estimated for RCO 7 was for 1996 and these fish are no longer in the fishery. The YCSs estimated since 1996 are therefore based on the assumption of mean recruitment for each year and the estimates of B_{mid99} and B_{mid00} are probably driven by the CELR CPUE index and the recent high landings.

In the last four fishing years (1998–99 to 2001–02), RCO 7 landings were been low compared to the previous five years. This suggests that although the abundance of red cod increased in the mid 1990s relative to the late 1980s, it may be declining again. Landings in 1999–00 (633 t) were the lowest recorded since 1986–87.

For RCO 7 a constant catch at the level of the current TACCs is unlikely to be attainable or sustainable in most years.

An analysis of recruitment–environment relationship showed that in RCO 7 there is a strong correlation between recruitment and environmental variables with a periodic 14 month time lag. The predictive power of the environment–abundance model proved to be more accurate for the most recent years in RCO 7 and may be useful for future assessments.

Summary of yield estimates (t), TACCs (t) and reported landings (t) of red cod for the most recent fishing year. MCY(1) from cYav method, MCY(2) from MIAEL method (range only given).

Fishstock	FMA			MCY(1)	MCY(2)	2004–05 Actual TACC	2004–05 Reported landings
RCO 1	Auckland (East) (West)	1 & 9	}	60		42	20
RCO 2	Central (East) (West)	2 & 8	}			500	423
RCO 3	South–East, Southland and Sub–Antarctic	3, 4, 5, & 6		4 400	2 418–13 330	12 389	4 211 –
RCO 7	Challenger	7		800	2 568–3 452	3 125	3 033
RCO 10	Kermadec	10		–		10	0
Total				5 260		16 066	7 687

6. FOR FURTHER INFORMATION

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