

## SCALLOPS COROMANDEL (SCA CS)

(*Pecten novaezelandiae*)



### 1. FISHERY SUMMARY

#### (a) Commercial fisheries

Scallops support regionally important commercial fisheries between Tauranga and Cape Rodney, the limits of the Coromandel fishery (SCA 7). Fishing is conducted within a number of discrete beds around Little Barrier Island, east of Waiheke Island (though not in recent years), at Colville, south and west of the Mercury Island group, and in the Bay of Plenty (principally off Waihi, and around Motiti and Slipper Islands). All commercial fishing is by dredge, with fishers preferring self-tipping “box” dredges to the “ring bag” designs used in Challenger and Chatham Island fisheries. The Coromandel commercial scallop fishing season runs from 15 July to 21 December each year.

A wide variety of effort controls and daily catch limits have been imposed in the past, but, since 1992, the fishery has been limited by explicit seasonal catch limits specified in meatweight (adductor muscle with roe attached), together with some additional controls on dredge size, fishing hours and non-fishing days. Catch and catch rates from the Coromandel fishery are variable both within and among years, a characteristic typical of scallop fisheries worldwide. Catch rates typically decline as each season progresses, but such declines are highly variable and depletion analysis cannot be used to assess start-of-season biomass.

Until the 1994 season, the minimum legal size for scallops taken commercially in northern (Coromandel and Northland) scallop fisheries was 100 mm shell length. From 1995 onwards, a new limit of 90 mm shell length was applied in the Coromandel (but not the Northland) fishery as part of a management plan comprising several new measures. Since 1980 when the fishery was considered to be fully-developed, landings have varied more than 30-fold from less than 50 t to over 1500 t (greenweight). The two lowest recorded landings were in 1999 and 2000.

Coromandel scallops were introduced into the QMS on 1 April 2002, with a TAC of 48 t, a TACC of 22 t, allowances of 7.5 t for recreational fisheries and 7.5 t for customary fisheries, and an allowance of 11 t for other sources of mortality. Northern scallop fisheries are managed under the QMS using individual transferable quotas (ITQ) that are proportions of the Total Allowable Commercial Catch (TACC). Catch limits and landings from the Coromandel fishery are shown in Table 1. Both northern scallop fisheries have been gazetted on the Second Schedule of the Fisheries Act 1996 which specifies that, for certain “highly variable” stocks, the Annual Catch Entitlement (ACE) can be increased within a fishing season. The TACC is not changed by this process and the ACE reverts to the “base” level of the TACC at the end of each season.

**Table 1: Catch limits, landed catch (t meatweight), and estimated catch (t greenweight) from the Coromandel fishery since 1974. The Coromandel commercial scallop season runs from 15 July to 21 December, inclusive. Data before 1986 are from Fisheries Statistics Unit (FSU) forms. Landed catch figures come from Licensed Fish Receiver Return (LFRR) forms and from the landed section of Catch Effort and Landing Return (CELR) forms whereas estimated catch figures come from the effort section of CELRs and are pro-rated to sum to the total CELR greenweight. “Hauraki” = 2X and 2W, “Mercury” = 2L and 2K, “Barrier” = 2R, 2S, and 2Q, “Plenty” = 2A–2I. Seasonal catch limits (since 1992) have been specified as ACE or on permits in meatweight (“Green” assumes the gazetted meatweight recovery conversion factor of 12.5% and probably overestimates the actual greenweight taken in most years). \* 1991 landings include about 400 t from Colville; –, no catch limits set, or no reported catch.**

Season	Catch limits (t)		Landed catch (t, meat)		Estimated catch (t green)				
	Meat	“Green”	LFRR	CELR	Total	Hauraki	Mercury	Barrier	Plenty
1974	–	–	–	–	26	0	26	0	0
1975	–	–	–	–	76	0	76	0	0
1976	–	–	–	–	112	0	98	0	14
1977	–	–	–	–	710	0	574	0	136
1978	–	–	–	–	961	164	729	3	65
1979	–	–	–	–	790	282	362	51	91
1980	–	–	–	–	1 005	249	690	23	77
1981	–	–	–	–	1 170	332	743	41	72
1982	–	–	–	–	1 050	687	385	49	80
1983	–	–	–	–	1 553	687	715	120	31
1984	–	–	–	–	1 123	524	525	62	12
1985	–	–	–	–	877	518	277	82	0
1986	–	–	162	–	1 035	135	576	305	19
1987	–	–	384	–	1 431	676	556	136	62
1988	–	–	182	–	1 167	19	911	234	3
1989	–	–	104	–	360	24	253	95	1
1990	–	–	153	–	903	98	691	114	0
1991	–	–	203	–	1 392	*472	822	98	0
1992	154	1 232	147	–	901	67	686	68	76
1993	132	1 056	62	–	455	11	229	60	149
1994	66	528	49	–	323	17	139	48	119
1995	86	686	88	79	574	25	323	176	50
1996	88	704	81	80	594	25	359	193	18
1997	105	840	94	89	679	26	473	165	15
1998	110	880	37	19	204	1	199	2	1
1999	31	248	8	7	47	0	12	17	18
2000	15	123	7	10	70	0	24	2	44
2001	22	176	22	20	161	1	63	85	12
2002	35	280	32	32	204	0	79	12	112
2003	58	464	58	58	451	63	153	13	223
2004	78	624	78	78	624	27	333	27	237
2005	118	968	119	121	968	21	872	75	0
2006	118	968	118	127	930	28	842	75	0

### (b) Recreational fisheries

There is an intense non-commercial (recreational and Maori) interest in scallops throughout the Coromandel and Northland fisheries. Non-commercial fishing for scallops occurs in suitable areas throughout the two fisheries, mostly in enclosed bays and harbours. Scallops are usually taken by diving using snorkel or SCUBA, although considerable amounts are also taken using small dredges. In some areas, especially in harbours, scallops can be taken by hand from the shallow subtidal and even the low intertidal zones (on spring tides), and, in storm events, scallops can be cast onto lee beaches in large numbers. To some extent, management of northern scallop fisheries has concentrated on spatial separation of commercial and amateur fisheries through the closure of harbours and enclosed waters to commercial dredging. There remain, however, areas of contention and conflict, some of which have been addressed using additional voluntary or regulated closures. Recreational regulations restrict the daily harvest (bag limit) to 20 per person, with a minimum legal size of 100

mm shell length. Until 2006, the recreational scallop season ran from 15 July to 14 February, but in 2007 the season was changed to run from 1 September to 31 March.

Currently, there are no reliable estimates of non-commercial harvest of scallops from the Coromandel or Northland fisheries. Estimates of catch by recreational fishers from the two northern scallop fisheries have been made on four occasions as part of recreational fishing (telephone and diary) surveys (Table 2). The Marine Recreational Fisheries Technical Working Group (FTWG) reviewed these surveys and recommended “that the telephone-diary estimates be used only with the following qualifications: 1) they may be very inaccurate; 2) the 1996 and earlier surveys contain a methodological error; and 3) the 1999/2000 and 2000/2001 estimates are implausibly high for many important fisheries.”

Given the above concerns about the reliability of non-commercial harvest estimates, it is difficult to make comparisons between the levels of commercial and non-commercial harvest. However, in 1993–94 the recreational harvest estimate was 60–70 t (greenweight) from the area shared with the Coromandel commercial fishery (Bradford, 1997). These estimates may include some Maori customary catch. Commercial landings from the Coromandel controlled fishery in the most comparable period (July to December 1994 scallop season) were 323 t, suggesting that, in that year, the recreational catch of scallops was about 16–18% of total removals. It is not known if these estimates are typical of the recreational catch, but the commercial catch was very low and 1993–94 may not have been a typical year.

**Table 2: Harvest estimates (number and greenweight) of scallops taken by recreational fishers in Coromandel and Northland (QMA 1) from the telephone-diary surveys conducted in 1993/94, 1996, 1999/2000, and 2000/01. The Marine Recreational Fisheries Technical Working Group considered that these estimates may be very inaccurate.**

Year	Coromandel			QMA 1 (Northland)			Reference
	No. of scallops	CV	Weight (t, green)	No. of scallops	CV	Weight (t, green)	
1993/94	626 000	0.14	60.0–70.0	374 000	0.17	40.0–60.0	Bradford (1997)
1996	614 000	0.12	62.0	272 000	0.18	32.0	Bradford (1998)
1999/200	257 000	1.01	30.1	634 000	0.34	69.8	Boyd & Reilly (2002)
2000/01	472 000	0.47	55.3	820 000	0.31	90.3	Boyd et al. (2004)

(c) **Maori customary fisheries**

Scallops were undoubtedly used traditionally as food by Maori, although quantitative information on the level of Maori customary take is not available.

(d) **Illegal catch**

There is no quantitative information on the level of illegal catch.

(e) **Other sources of mortality**

The box dredges in use throughout the Coromandel fishery have been found to be considerably more efficient than ring-bag or Keta-Ami dredges, in the generally sandy conditions prevalent in the fishery. However, scallops encountered by box dredges showed modest reductions in growth rate compared with scallops collected by divers, and their mortality was high (up to about 50% for larger size classes). Stochastic modelling suggested that, of the three dredge designs tested, box dredges would generate the greatest yield-per-recruit and catch rates. The incidental mortality caused by dredging substantially changed the shape of yield-per-recruit curves for Coromandel scallops, causing generally asymptotic curves to become domed, and decreasing estimates of  $F_{max}$  and  $F_{0.1}$ . More recent field experiments and modelling suggest that dredging reduces habitat heterogeneity, increases juvenile mortality, makes yield-per-recruit curves even more domed, and decreases estimates of  $F_{max}$  and  $F_{0.1}$  even further.

## 2. BIOLOGY

*Pecten novaezelandiae* is one of several species of “fan shell” bivalve molluscs found in New Zealand waters. Others include queen scallops and some smaller species of the genus *Chlamys*. *P. novaezelandiae* is endemic to New Zealand, but is very closely related to the Australian species *P. fumatus* and *P. modestus*. Scallops of various taxonomic groups are found in all oceans and support many fisheries world-wide. Most undergo large population fluctuations.

Scallops are found in a variety of coastal and intertidal habitats, but particularly in semi-enclosed areas where circulating currents are thought to retain larvae. After the planktonic larval phase and a relatively mobile phase as very small juveniles, scallops are largely sessile and move actively mainly in response to predators. They may, however, be moved considerable distances by currents and storms and are sometimes thrown up in large numbers on beaches.

Scallops are functional hermaphrodites, and become sexually mature at a size of about 60–70 mm shell length. They are extremely fecund and may spawn several times each year. Fertilisation is external and larval development lasts for about 3 weeks. Initial settlement occurs when the larva attaches via a byssus thread to filamentous material or dead shells on or close to the seabed. The major settlement of spat in northern fisheries usually takes place in early January. After growth to about 5 mm, the byssus is detached and, after a highly mobile phase as a small juvenile, the young scallop takes up the relatively sedentary adult mode of life.

The very high fecundity of this species, and likely variability in the mortality of larvae and pre-recruits, leads to great variability in annual recruitment. This, combined with variable mortality and growth rate of adults, leads to scallop populations being highly variable from one year to the next, especially in areas of rapid growth where the fishery may be supported by only one or two year classes. This variability is characteristic of scallop populations world-wide, and often occurs independently of fishing pressure.

The growth of scallops within the Coromandel fishery is variable among areas, years, seasons and depths, and probably among substrates. In the Hauraki Gulf scallops have been estimated to grow to 100 mm shell length in 18 months or less whereas this can take three or more years elsewhere. In some years, growth is very slow, whereas in others it is very rapid. There is a steep relationship with depth and scallops in shallow water grow much faster than those in deeper water. This is not a simple relationship, however, as scallops in some very deep beds (e.g., Rangaunu Bay and Spirits Bay in the far north, both deeper than 40 m) appear to grow at least as fast as those in favourable parts of the Coromandel fishery. Food supply undoubtedly plays a role.

A variety of studies suggest that average natural mortality in the Coromandel fishery is quite high at  $M = 0.50 \text{ y}^{-1}$  (instantaneous rate), and maximum age in unexploited populations is thought to be about 6 or 7 years. Biological parameters are presented in Table 3.

**Table 3: Estimates of biological parameters.**

Stock	Estimates			Source
<b>Natural mortality, M</b>				
Motiti Island	0.4–0.5			Walshe (1984)
Coromandel Fishery	Mean 0.5			Cryer (2001)
<b>Weight = a(length)<sup>b</sup></b>				
	<b>a</b>	<b>b</b>		
Coromandel fishery	0.00042	2.662		Cryer & Parkinson (1999)
<b>von Bertalanffy parameters</b>				
	<b>L<sub>∞</sub></b>	<b>K</b>	<b>t<sub>0</sub></b>	
Motiti Island (1981–82)	140.6	0.378	-0.0004	Walshe (1984)
Hauraki Gulf (1982–83)	115.9	1.200	0.0000	Walshe (1984)
Whitianga (1982)	114.7	1.210	0.0000	Data of L.G. Allen, analysed by Cryer & Parkinson (1999)
Whitianga (1983)	108.1	1.197	0.0000	Data of L.G. Allen, analysed by Cryer & Parkinson (1999)
Whitianga (1984)	108.4	0.586	0.0000	Data of L.G. Allen, analysed by Cryer & Parkinson (1999)
Coromandel fishery (1992–97)	108.8	1.366	0.0000	Cryer & Parkinson (1999)
Whitianga mean depth 10.6 m	113.5	1.700	0.0000	Cryer & Parkinson (1999)
Whitianga mean depth 21.1 m	109.0	0.669	0.0000	Cryer & Parkinson (1999)
Whitianga mean depth 29.7 m	110.3	0.588	0.0000	Cryer & Parkinson (1999)

### 3. STOCKS AND AREAS

Scallops are distributed throughout the Coromandel fishery area in suitable habitat, although some of the beds are persistent and others are ephemeral. Scallops inhabit waters of up to about 60 m deep (apparently up to 85 m at the Chatham Islands), but are more common in depths of 10 to 45 m on substrates of shell gravel, sand or, in some cases, silt. The extent to which the various beds or populations are separate reproductively or functionally is not known.

### 4. STOCK ASSESSMENT

#### (a) Estimates of fishery parameters and abundance

Fishing mortality has sometimes been quite high in the Coromandel fishery. The average direct fishing mortality on scallops 100 mm or longer in the Mercury Bay beds (1978–1992) was estimated at  $F_{est} = 1.0 \text{ y}^{-1}$  (instantaneous rate, assuming  $M \sim 0.4$ ). Using data on the same size class from 1980 to 1997 and an assumed rate of  $M = 0.50 \text{ y}^{-1}$  spread throughout the year, the estimated average direct fishing mortality for the Mercury Bay bed was  $F_{est} = 1.26 \text{ y}^{-1}$ , and for the Little Barrier Island bed was  $F_{est} = 1.08 \text{ y}^{-1}$ . Estimated fishing mortality between 1998 and 2002 was considerably lower than these averages (0.01–0.45  $\text{y}^{-1}$ ). There is no known stock-recruit relationship for Coromandel scallops.

#### (b) Biomass estimates

Virgin biomass,  $B_0$ , and the biomass that will support the maximum sustainable yield,  $B_{MSY}$ , have not been estimated and are probably not appropriate reference points for a stock with highly variable recruitment and growth such as scallops.

There have been annual surveys and assessments of Coromandel scallops since 1992 (except for 2000), in support of a CAY management strategy. Assessments are based on pre-season biomass surveys conducted by diving and/or dredging.

**Table 4: Estimated recruited biomass (at the time of surveys) of scallops of 95 mm or more shell length in the Coromandel fishery since 1980 using historical average dredge efficiency. – indicates no survey in a given year, \* not all beds surveyed, estimate of total biomass probably significantly biased low. Bay of Plenty landings come from beds at Waihi, Motiti, and Papamoa.**

Year	Biomass (t greenweight)				
	Hauraki	Whitianga	Little Barrier	Bay of Plenty	Total
1980	–	1197	–	–	–
1981	–	1092	–	–	–
1982	–	725	–	–	–
1983	–	998	–	–	–
1984	800	1092	–	–	*1892
1985	2000	966	–	–	*2966
1986	1500	1313	–	–	*2813
1987	–	1628	–	–	–
1988	–	–	–	–	–
1989	–	–	–	–	–
1990	608	767	–	–	*1375
1991	266	824	–	–	*1090
1992	73	1272	–	–	*1345
1993	41	748	–	735	*1524
1994	3	481	–	153	*637
1995	26	445	258	509	1277
1996	28	619	346	241	1244
1997	508	623	402	269	1839
1998	506	641	99	132	1414
1999	18	176	19	87	325
2000	–	–	–	–	–
2001	19	142	152	70	403
2002	90	255	85	70	513
2003	160	428	146	206	1287
2004	471	2546	119	340	3479
2005	475	5036	282	518	6311
2006	685	4397	321	237	5640

Until 1997, assessments for the Coromandel fishery were based on Provisional Yield (PY, estimated as the lower bound of a 95% confidence distribution for the estimated start-of-season biomass of scallops 100 mm or more shell length). Experiments and modelling showed this method to be sub-optimal. New estimates of the reference fishing mortality rates  $F_{0.1}$ ,  $F_{40\%}$  and  $F_{max}$  were therefore made, taking into account experimental estimates of incidental fishing mortality. For assessments since 1998, CAY was estimated using these reference fishing mortality rates, and CAY supplanted PY as a yield estimator. Recent experimentation and modelling of juvenile mortality in relation to habitat heterogeneity suggest that even these more conservative reference fishing mortality rates may be too high.

Diver surveys of scallops were conducted in June 2006 at selected scallop beds in Northland and Coromandel recreational fishing areas (Williams et al., 2006a). For the four small beds (total area of 4.64 km<sup>2</sup>) surveyed in the Coromandel fishery, start-of-season biomass of scallops over 100 mm shell length was estimated to be 128 t greenweight (16 t meatweight) with a CV of 26%.

(c) **Estimation of Maximum Constant Yield (MCY)**

MCY has not been estimated for Coromandel scallops and would probably be close to zero.

(d) **Estimation of Current Annual Yield (CAY)**

Recent management of Coromandel scallops has been based on a CAY approach. Since 1998, catch limits have been adjusted in line with estimated start-of-season recruited biomass and an estimate of CAY made using the version of the Baranov catch equation given by Cryer & Morrison (1997):

$$CAY = \frac{F_{ref}}{F_{ref} + \frac{5M}{12}} * \left[ 1 - e^{-\left(F_{ref} + \frac{5M}{12}\right)} \right] * B_{jul}$$

Where,  $F_{ref}$  is a reference fishing mortality ( $F_{0.1}$ ,  $F_{max}$  or  $F_{40\%}$ ) and  $B_{jul}$  is the start-of-season recruited biomass (scallops of 90 mm or more shell length). This approach is specific to the 5 month Coromandel scallop fishing season. Because of the uncertainty over biomass estimates, growth, and mortality in a given year, and appropriate reference rates of fishing mortality, CAY estimates are derived for two different scenarios.

**Average outlook, excluding habitat effects**

The start-of-season recruited biomass of scallops 90 mm in shell length or greater in the Coromandel fishery was predicted to be 12 203 t (greenweight) and 1531 t (meatweight) in 2006 (Williams et al., 2006b). CAY was calculated using these biomass estimates and each of the reference fishing mortality rates  $F_{0.1}$ ,  $F_{max}$ , and  $F_{40\%}$  as follows:

For  $F_{40\%}$  (0.514),      CAY = 0.7116 \* 0.5144 \* 12203 (1531) = 4503 t (green) or 560 t (meat)

For  $F_{0.1}$  (0.431),      CAY = 0.6741 \* 0.4724 \* 12203 (1531) = 3918 t (green) or 488 t (meat)

For  $F_{max}$  (0.683),      CAY = 0.7666 \* 0.5898 \* 12203 (1531) = 5562 t (green) or 692 t (meat)

These estimates of CAY would have a CV at least as large as that of the estimate of start-of-season recruited biomass (20–25%), are sensitive to assumptions about dredge efficiency, growth, and expected recovery of meatweight from greenweight, and relate to the surveyed beds only. The sensitivity of excluding areas of low density has not been calculated, but excluding stations with density < 0.04 m<sup>-2</sup> reduced the time of survey biomass estimate by 13%. The level of risk to the putative Coromandel scallop stock of fishing at the estimated CAY level cannot be determined.

### Average outlook, including putative habitat effects

Modelling the “feedback” effects of habitat modification by the dredge method on juvenile mortality in scallops over an assumed “critical phase” lasting 8 weeks led to estimates of  $F_{0.1} = 0.274$ ,  $F_{max} = 0.349$ , and  $F_{40\%} = 0.356$ . CAY including habitat effects as well as incidental effects was calculated using each of these reference rates of fishing mortality:

For  $F_{40\%}$  (0.356),      CAY =  $0.6308 * 0.4313 * 12203$  (1531) = 3347 t (green) or 417 t (meat)

For  $F_{0.1}$  (0.274),      CAY =  $0.5681 * 0.3827 * 12203$  (1531) = 2675 t (green) or 333 t (meat)

For  $F_{max}$  (0.349),      CAY =  $0.6262 * 0.4272 * 12203$  (1531) = 3291 t (green) or 410 t (meat)

These estimates of CAY would have a CV at least as large as that of the estimate of start-of-season recruited biomass (20–25%), are sensitive to assumptions about dredge efficiency, growth, and expected recovery of meatweight, to the duration of any habitat-mediated increase in juvenile mortality, and relate to the surveyed beds only. The sensitivity of excluding areas of low density has not been calculated, but excluding stations with density  $< 0.04 \text{ m}^{-2}$  reduced the time of survey biomass estimate by 13%. The level of risk to the putative Coromandel scallop stock of fishing at the estimated CAY level cannot be determined.

#### (e) Other yield estimates and stock assessment results

The estimation of Provisional Yield (PY) is no longer accepted as appropriate, and assessments since 1998 have used a CAY approach.

Stochastic yield-per-recruit (YPR) and spawning-stock-biomass-per-recruit (SSBPR) modelling has been conducted for the Coromandel scallop fishery, including the incidental effects on growth and mortality of the dredge method in use throughout the fishery. Estimates of reference rates of fishing mortality from this study have been used to estimate CAY since 1998. More recent experimental and modelling studies indicate that even these reference rates of fishing mortality may be too high if habitat effects and juvenile scallop mortality are taken into account, causing a positive bias in CAY. CAY may also be over-estimated when either the efficiency of the dredge used during the survey is greater than that assumed in calculations (i.e., the multiplier used to account for dredge efficiency is optimistic), or the density of scallops is low and part of the biomass occurs at a density not viable for commercial fishing.

## 5. STATUS OF THE STOCKS

Estimates of current biomass for the Coromandel fishery are available (from a 2006 survey) but the only reference biomass that might be calculated is average recruited biomass. Scallop biomass can be expected to vary from one year to the next, so the long-run average is difficult to estimate and not necessarily a good indicator. However, biomass estimates around the turn of the century were consistently at or near the lowest on record and it seems reasonable to conclude that the population was, for unknown reasons, at a very low ebb. In contrast, following reasonable increases in biomass, catch rate, and condition of scallops in 2003 and, especially, 2004, the biomass in 2005 (almost regardless of what is assumed about dredge efficiency) was the highest on record and probably higher than in the mid-1980's when not all of the beds were surveyed. This remarkable resurgence was strongest at the Mercury Islands beds, but most beds showed some increase in density. The 2006 survey results suggest maintenance of this high biomass, especially at the Mercury Islands beds. We do not understand the processes that have resulted in such large fluctuations in scallop abundance. Given these dramatic changes, it is not known if landings at the level of CAY are sustainable, and the biomass that will support the maximum sustainable yield is probably not an appropriate reference point for a stock with highly variable recruitment and growth such as scallops.

Yield estimates, TACC, ACE and reported landings are summarised in Table 5.

**Table 5: Yield estimates, TACC, ACE and reported landings, for the 2005/06 fishing year, for scallops SCA CS.**

Fishstock	QMA	MCY	2006	TACC	ACE	2006
			CAY ( $F_{0.1}$ )			Landings
SCA CS	Coromandel	N/A	333–488	22	118	127

## 6. FOR FURTHER INFORMATION

- Boyd, R.O.; Gowing, L.; Reilly, J.L. (2004). 2000-2001 national marine recreational fishing survey: diary results and harvest estimates. *Draft New Zealand Fisheries Assessment Report*. 2004/xx. 81 p.
- Boyd, R.O.; Reilly, J.L. (2002). 1999/2000 National marine recreational fishing survey: harvest estimates. *Draft New Zealand Fisheries Assessment Report*. 2002/xx 28 p.
- Bradford, E. (1997). Estimated recreational catches from Ministry of Fisheries North region marine recreational fishing surveys, 1993-94. *New Zealand Fisheries Assessment Research Document* 1997/7. 16 p.
- Bradford, E. (1998). Harvest estimates from the 1996 national marine recreational fishing surveys. *New Zealand Fisheries Assessment Research Document* 1998/16. 27 p.
- Bull, M.F. (1991a). New Zealand. pp 853–859 in Shumway S.E. (ed) *Scallops: biology, ecology and aquaculture*. Developments in Aquaculture & Fisheries Science, 21. Elsevier. Amsterdam. 1095 p.
- Bull, M.F. (1991b). Report on a survey of the scallop resource at the Chatham Islands 22 April – 5 May 1990. *Central Fisheries Region Internal Report* No. 16. 29 p.
- Cryer, M. (1994). Estimating CAY for northern commercial scallop fisheries: a technique based on estimates of biomass and catch from the Whitianga bed. *New Zealand Fisheries Assessment Research Document* 1994/18. 21 p. (Draft report held at NIWA library, Wellington.)
- Cryer, M. (2001a). Coromandel scallop stock assessment for 1999. *New Zealand Fisheries Assessment Report* 2001/9. 18 p.
- Cryer, M. (2001b). An appraisal of an in-season depletion method of estimating biomass and yield in the Coromandel scallop fishery. *New Zealand Fisheries Assessment Report* 2001/8. 28 p.
- Cryer, M. (2002). Northland and Coromandel scallop stock assessments for 2001. *New Zealand Fisheries Assessment Report* 2002/60. 20 p.
- Cryer, M.; Breen, P.A.; Kendrick, T.H. (2003b). Models to evaluate fishing strategies for northern scallop fisheries. Final Research Report for Ministry of Fisheries Research Project MOF2000/03E. 61 p. (Unpublished report held by Ministry of Fisheries, Wellington).
- Cryer, M.; Morrison, M. (1997). Yield per recruit in northern commercial scallop fisheries: inferences from an individual-based population model and experimental estimates of incidental impacts on growth and survival. Final Report to Ministry of Fisheries on Project AKSC03. 67 p. (Unpublished report held by Ministry of Fisheries, Wellington).
- Cryer, M.; Morrison, M.; Davies, N.M. (2003a). Including incidental effects in fisheries models can have major implications for management advice: an example based on scallop dredging. Submitted to Canadian Journal of Fisheries and Aquatic Sciences, also presented to 2003 meeting of New Zealand Marine Sciences Society.
- Cryer, M.; Parkinson, D.M. (1999). Dredge surveys and sampling of commercial landings in the Northland and Coromandel scallop fisheries, May 1998. *NIWA Technical Report* 69. 63 p.
- Cryer, M.; Parkinson, D.M. (2001). Dredge surveys of scallops in the Northland and Coromandel scallop fisheries, April–May 2001. Working Document for Ministry of Fisheries Shellfish Fishery Assessment Working Group Meeting June 2001. 40 p. (Unpublished report held by Ministry of Fisheries, Wellington).
- Cryer, M.; Parkinson, D.M. (2004a). Dredge survey and stock assessment for the Coromandel scallop fishery, 2003. Final Research Report for Ministry of Fisheries project SCA2002/01. 36 p. (Unpublished report held by Ministry of Fisheries, Wellington).
- Cryer, M.; Parkinson, D.M. (2004b). Dredge survey and stock assessment for the Coromandel scallop fishery, 2004. Research Progress Report and working document for Shellfish Fishery Assessment Working Group (June 2004), Ministry of Fisheries project SCA2003/01. 36 p. (Unpublished report held by Ministry of Fisheries, Wellington).
- Cryer, M.; Parkinson, D.M. (2006). Biomass surveys and stock assessments for the Coromandel and Northland scallop fisheries, 2005. *New Zealand Fisheries Assessment Report* 2006/34. 53 p.



- Diggles, B.; Chang, H.; Smith, P.; Uddstrom, M.; Zeldis, J. (2000). A discolouration syndrome of commercial bivalve molluscs in the waters surrounding the Coromandel Peninsula. Final Research Report for Ministry of Fisheries Project MOF1999/04B. (Unpublished report held by Ministry of Fisheries, Wellington).
- Hancock, D.A. (1973). The relationship between stock and recruitment in exploited invertebrates. *Rapports et Process Verbeaux de la Reunion du Conseil International pour l'Exploration de la Mer* 164: 113–131.
- Morrison, M. (1998). Population dynamics of the scallop, *Pecten novaezelandiae*, in the Hauraki Gulf. Unpublished PhD thesis, University of Auckland, Auckland, New Zealand. 157 p.
- Orensanz, J.M.; Parma, A.M.; Iribarne, O.O. (1991). Population dynamics and management of natural stocks. Ch. 13 in Shumway, S.E. (ed.) *Scallops: biology ecology and aquaculture. Developments in Aquaculture and Fisheries Science*, Elsevier, Amsterdam.
- Peterson, C.H.; Summerson, H.C. (1992). Basin-scale coherence of population dynamics of an exploited marine invertebrate, the bay scallop: implications of recruitment limitation. *Marine Ecology Progress Series* 90: 257–272.
- Peterson, C.H.; Summerson, H.C.; Leuttich, R.A. (1996). Response of Bay scallops to spawner transplants: a test of recruitment limitation. *Marine Ecology Progress Series* 132: 93–107.
- Shumway, S.E. (ed) (1991). *Scallops: biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Science*, 21. Elsevier. Amsterdam. 1095 p.
- Shumway, S.E.; Sandifer, P.A. (eds) (1991). *Scallop biology and culture. Selected papers from the 7th International Pectinid Workshop. World Aquaculture Society, Baton Rouge, Louisiana, USA.*
- Talman, S.G.; Norkko, A.; Thrush, S.F.; Hewitt, J.E. (2004) Habitat structure and the survival of juvenile scallops *Pecten novaezelandiae*: comparing predation in habitats with varying complexity. *Marine Ecology Progress Series* 269: 197–207.
- Thrush, S.F.; Hewitt, J.E.; Cummings, V.J.; Dayton, P.K.; Cryer, M.; Turner, S.J.; Funnell, G.A.; Budd, R.G.; Milburn, C.J.; Wilkinson, M.R. (1998). Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. *Ecological Applications* 8: 866–879.
- Thrush, S.F.; Hewitt, J.E.; Funnell, G.A.; Cummings, V.J.; Ellis, J.; Schultz, D.; Talley, D.; Norkko, A. (2001). Fishing disturbance and marine biodiversity: the role of habitat structure in simple soft-sediment systems. *Marine Ecology Progress Series* 223: 277–286.
- Walshe, K.A.R. (1984). A study to determine the optimum number of licences for the Tauranga commercial scallop fishery based on a optimum yield estimate. Unpublished report for Diploma in Business and Administration, Massey University, Palmerston North, New Zealand.
- Waller, T.R. (1991). Evolutionary relationships among commercial scallops (Mollusca: Bivalva: Pectinidae). pp 1–74 in Shumway S.E. (ed) *Scallops: biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Science*, 21. Elsevier. Amsterdam. 1095 p.
- Williams, J.R. (2005). Reproductive ecology of the scallop, *Pecten novaezelandiae*. Unpublished PhD thesis, University of Auckland, Auckland, New Zealand. 134 p.
- Williams, J.R.; Babcock, R.C. (2004a). Patterns of reproduction and spawning behaviour for scallops, *Pecten novaezelandiae*, in northeastern New Zealand. *Journal of Shellfish Research* 23: 318.
- Williams, J.R.; Babcock, R.C. (2004b). Comparison of multiple techniques to evaluate reproductive variability in a marine bivalve: application to the scallop *Pecten novaezelandiae*. *Marine and Freshwater Research* 55: 457–468.
- Williams, J.R.; Babcock, R.C. (2005). Assessment of size at maturity and gonad index methods for the scallop *Pecten novaezelandiae*. *New Zealand Journal of Marine and Freshwater Research* 39: 851–864.
- Williams, J.R.; Tuck, I.D.; Carbines, G.D. (2006a) Abundance of scallops in Northland and Coromandel recreational fishing areas, 2006. Draft New Zealand Fisheries Assessment Report for Ministry of Fisheries project SAP2005/10. 23 p. (Unpublished report held by Ministry of Fisheries, Wellington.)
- Williams, J.R.; Tuck, I.D.; Parkinson, D.M. (2006b). Biomass surveys and stock assessments for the Coromandel and Northland scallop fisheries, 2006. Draft New Zealand Fisheries Assessment Report for Ministry of Fisheries projects SCA2005/01 and SCA2005/02. 41 p. (Unpublished report held by Ministry of Fisheries, Wellington.)