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Dredge surveys and estimates of yield for the Northland and Coromandel scallop fisheries, 2001

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5. **Project Leader:** Martin Cryer

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Start date: March 2001
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7. **Executive Summary:**

This report covers all aspects of the assessment of Northland and Coromandel scallop fisheries in 2001, except for analysis of historical dredge efficiency data.

The Northland scallop fishery was surveyed by dredge in April–May 2001 (*see* attached draft Technical Report). Estimated start-of-season biomass (scallops of 100 mm or greater shell length) was 871 t with a *c.v.* of 27% (assuming an average dredge efficiency equal to the highest previous estimate in the fishery). The Coromandel scallop fishery was surveyed by dredge in May 2001 (*see* attached draft Technical Report). Estimated start-of-season biomass (scallops of 90 mm or greater shell length) was 577 t with a *c.v.* of 27% (assuming average dredge efficiency on sand and mud equal to the highest previous estimates on these substrates). These are amongst the lowest estimates of recruited biomass for both fisheries, even when recalculated using historical average dredge efficiency.

There is no new information on growth rates because no tagged scallops were returned during the preceding fishing year (Objective 2).

For the Northland fishery, $CAY_{F0.1}$ was estimated as 323 t (greenweight) or 44 t (meatweight). For the Coromandel fishery, $CAY_{F0.1}$ was estimated as 209 t (greenweight) or 28 t (meatweight). For historical comparison only, Provisional Yield (PY, size at recruitment = 100 mm) was estimated as 82 t (greenweight) or 11 t (meatweight) (Objective 3, *see* attached draft FAR).

8. Objectives:

SCA2000/01 (Coromandel fishery):

1. To carry out a stock assessment of scallops (*Pecten novaezelandiae*) in the Coromandel fishery, including estimating abundance and sustainable yields.

Specific Objectives:

1. To estimate the absolute abundance and population size frequency of scallops in the main scallop beds by 1 May 2001. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance is 20%.

2. To estimate growth rate and mortality of scallops with the inclusion of recapture data (from a previous tag-recapture project) collected during the 2000/2001 fishing year.

3. To estimate yield following the completion of the survey described in objective 1.

SCA2000/02 (Northland fishery):

1. To carry out a stock assessment of scallops (*Pecten novaezelandiae*) in the Northland fishery, including estimating abundance and sustainable yields.

Specific Objectives:

1. To estimate the absolute abundance and population size frequency of scallops in the main scallop beds by 1 May 2001. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance is 20%.

2. To estimate growth rate and mortality of scallops with the inclusion of recapture data (from a previous tag-recapture project) collected during the 2000/2001 fishing year.

3. To estimate yield following the completion of the survey described in objective 1.

9. Methods:

As described in attached draft Technical Report and draft FARs

10. Results:

As described in attached draft Technical Report and draft FARs.

11. Conclusions:

As described in executive summary, and described in more detail in the attached draft Technical Report and draft FARs.

12. Publications:

See attached draft Technical Report and draft FAR. NIWA seeks permission to publish some of these results formally.

13. Data Storage:

Raw data are held, with appropriate documentation, on the fully secured and backed up Empress database *trawl* and are most accessible through the view *scallop*.

Northland and Coromandel scallop stock assessments for 2001

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New Zealand Fisheries Assessment Report 2001/xx
March 2002

EXECUTIVE SUMMARY

Cryer, M. (2001). Northland and Coromandel scallop stock assessments for 2001.
***New Zealand Fisheries Assessment Report 2001/xx*. 20 p.**

The Northland and Coromandel scallop fisheries were surveyed by dredge in April–May 2001 to predict start-of-season recruited biomass. Areas thought unlikely to support commercial fishing in the 2001 season were not surveyed. Dredge efficiency was not estimated directly, but assumed based on precautionary treatment of historical estimates in each fishery. For the Northland fishery, start-of-season biomass (scallops 100 mm or more shell length) was estimated at 871 t greenweight with a *c.v.* of 27%, or 118 t meatweight at an assumed average recovery rate of 13.5% (meat from green). For the Coromandel fishery, start-of-season biomass (scallops 90 mm or more shell length) was estimated at 577 t greenweight with a *c.v.* of 27%, or 78 t meatweight at an assumed average recovery rate of 13.5%. For comparison with historical surveys, start-of-season biomass (scallops 100 mm or more shell length) was estimated as 195 t with a *c.v.* of 29%. Estimates of recruited biomass in 2001 are among the lowest on record for both fisheries, although slightly better than the most recent surveys in both fisheries (1998 in the Northland fishery and 1999 in the Coromandel fishery). Using estimates of $F_{0.1}$ from stochastic yield-per-recruit models as reference rates of fishing mortality, yield for the Northland fishery was estimated as CAY = 45 t (meatweight), and yield for the Coromandel fishery was estimated as CAY = 28 t. Provisional Yield (PY) for the Coromandel fishery was estimated (for historical comparison) as PY = 11 t (meatweight). Estimates of biomass and yield for both fisheries are sensitive to assumptions about dredge efficiency in 2001, to exclusion of areas of low scallops density (where it is assumed uneconomic to fish) and to the selection of a reference rate of fishing mortality. The gazetted conversion factor of 8 (equivalent to a recovery of 12.5%) also leads to lower estimates of yield in meatweight than the estimated recovery rate of 13.5%.

1. INTRODUCTION

1.1 Overview

This report summarises research and catch information for the Northland and Coromandel scallop fisheries (Ahipara to Cape Rodney and Cape Rodney to Town Point, respectively). Yield estimates for the commercial season beginning July 2001 are derived using methods after Cryer (1994), Cryer & Morrison (1997), and Annala et al. (2000). This work was funded by the Ministry of Fisheries under projects SCA2000/01 and SCA2000/02.

1.2 Description of the fishery

Scallops support regionally important commercial fisheries and an intense non-commercial interest off the north-east coast of the North Island. The Northland fishery is managed under the Quota Management System (QMS) whereas the Coromandel fishery (including the Hauraki Gulf) is a Controlled Fishery. The dividing line between the two runs from Cape Rodney to the northernmost tip of Great Barrier Island (Figure 1). All commercial fishing is by dredge and self-tipping "box" dredges are preferred to the ring bag designs in common use in southern fisheries. Many effort controls and daily catch limits have been imposed in the past, but both fisheries are limited by explicit seasonal catch limits specified in meatweight, together with some additional controls on dredge size, fishing hours, and (in the Coromandel fishery) non-fishing days. Catch and catch rates from both fisheries are variable both within and among years, a characteristic of scallop fisheries world-wide (Shumway & Sandifer 1991).

Fishing in the Northland fishery is within discrete beds in Spirits Bay, Tom Bowling Bay, Great Exhibition Bay, Rangaunu Bay, Doubtless Bay, Stevenson's Island, the Cavalli Passage, Bream Bay, and the coast between Mangawhai and Pakiri Beach. In the Coromandel fishery, the main beds are found north of Whitianga (at the Mercury Islands), east of Waiheke Island, around Little Barrier and Great Barrier Islands, and in the Bay of Plenty (principally off Waihi, and around Motiti and Slipper Islands). Recreational and Maori customary fishing is undertaken in suitable areas throughout both fisheries, more especially in enclosed bays and harbours, many of which are closed to commercial fishing.

The minimum legal size (MLS) for scallops for commercial and amateur fishers throughout the both fisheries was 100 mm until 1995. Starting with the 1995 commercial season in July 1995, the MLS for scallops taken commercially from the Coromandel fishery was reduced to 90 mm as part of a package of measures which also included further voluntary closed areas (VCAs) and reduced commercial catch limits. This package was introduced to address concerns expressed by all user groups over the impact of scallop dredging on juvenile scallops.

1.3 Literature review

General descriptions of the biology of the New Zealand scallop, *Pecten novaezelandiae*, were given by Bull (1988) and Cryer (1994), and little new information on the biology has become available subsequently other than an unpublished Ph.D. thesis by Morrison (1999). The New Zealand scallop is one of several species of "fan shell" bivalve molluscs found in New Zealand waters. They have a characteristic round shell with a flat upper valve and a deeply concave lower valve. Scallops inhabit waters to about 60 m deep (to 85 m in the Chatham Islands), but are more common in the Coromandel fishery in depths of 10 to 30 m. Growth rates are spatially and temporally variable; growth to 100 mm takes between 1.5 and 3.5 years. The maximum age of scallops in unexploited populations is thought to be about 6 or 7 years.

P. novaezelandiae is an hermaphroditic species, each individual carrying both male and female gonads at the same time. Most individuals are sexually mature at about 60 mm, although larger individuals have disproportionately larger gonads. They are extremely fecund and can spawn several times each year (although not all of these spawning events lead to successful spat settlement). Larval development lasts for about 3 weeks, depending on water temperature. Initial spat settlement is by byssus thread attachment to some surface free of sediment (shell hashes, hydroids, spat bags etc.). The characteristic scallop shell does not develop until a few days after the spat loses the byssus thread and settles to the seabed.

Scallops grow rapidly (albeit with considerable variation), have high natural mortality ($M \sim 0.50\ y^{-1}$), and exhibit variable recruitment. Such a life history results in fluctuating biomass, catch, and CPUE in most fisheries for scallops, and reliance on relatively few year-classes (Caddy & Gulland 1983, Orensanz et al. 1991, Shumway & Sandifer 1991). New Zealand stocks are not extreme examples, but Cryer (1994) examined data from 1978 to 1992 and found that recruited biomass in the Coromandel fishery could not be predicted from historical biomass estimates, nor even from the biomass in the previous year together with estimates of intervening removals by commercial fishing.

2. Review of the fishery

2.1 TACCs, catch, landings, and effort data

The Northland fishery is managed under the QMS using individual transferable quotas (ITQ) that are proportions of the Total Allowable Commercial Catch (TACC) (Table 1). The Coromandel fishery is managed as a Controlled Fishery, and catch is limited by seasonal limits which have the same effect as a TACC (Table 2). Seasons run from 15 July to 14 February (Northland fishery) or 21 December (Coromandel fishery). Catch rates are variable both within and among seasons, but the relationship between biomass and CPUE is complex and (declines in) CPUE cannot be used to estimate biomass within a season (Cryer 2001b). Effort data are, therefore, not presented.

2.2 Other information

The incidental impacts of commercial scallop dredges were examined in 1996–97 (Cryer & Morrison 1997). Individual-based modelling and stochastic yield-per-recruit (YPR) analysis suggest that neither the 100 mm MLS in force in Northland nor the PY method of estimating yield were optimal (in terms of maximising long term average landings).

2.3 Recreational and Maori customary fisheries

There is an intense amateur interest in scallops throughout the Northland and Coromandel fisheries. Amateurs usually dive or use small dredges but, in some circumstances, they collect scallops by hand from intertidal areas. 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 were addressed between 1995 and 1999 using additional voluntary or regulated closures.

Recreational catch in 1993–94 from the area shared with the Northland commercial fishery (Bradford 1997) was 40–60 t (green weight). Commercial landings from the Northland fishery in the most comparable period (July 1994 to February 1995 scallop season) were about 1300 t, suggesting that, in that year, the recreational catch of scallops was probably less than 5% of total removals. Estimates of catch by recreational fishers in 1993–94 (Bradford 1997) are 60–70 t from the area shared with the Coromandel commercial fishery. Commercial landings from the Coromandel controlled fishery in the most comparable period (July to December 1994 scallop season) were about 300 t, suggesting that, in that year, the recreational catch of scallops was about 20% of total removals.

2.4 Other sources of fishing mortality

Quantitative information is available on the incidental impacts on scallop growth and mortality of encounters with commercial dredges of several designs (Cryer & Morrison 1997). Individual-based population modelling and yield-per-recruit analysis strongly suggest that incidental effects, especially on mortality rates, greatly affect yield from scallop dredge fisheries. Despite the high incidental mortality rates associated with the current box dredge, this design was found to be the best of the three tested (for a MLS of 85 mm or more) in terms of yield-per-recruit, largely as a result of its higher catching efficiency compared with the ring-bag and Japanese "Keta Ami" designs. This work suggested that the current MLS of 90 mm was close to optimal (in terms of maximising long term average landings) for the Coromandel fishery.

Table 1**: Catch limits and landings (t green weight or meat weight as specified) from the Northland Scallop Fishery since 1980. "Landed" figures come from the landed section of the Catch Effort and Landing (CELR) form and "Estimated" figures from the effort section and are pro-rated to sum to the total landed green weight. "Whangarei" includes all beds south of Cape Brett, "Far North" includes all beds from Cape Brett to North Cape, and "Spirits Bay" includes all beds to the west of North Cape. Catch limits for 1996 were specified on permits in meat weight, and were for 1997 specified as a formal TACC (in meat weight). The approximate green weight equivalent given here assumes the gazetted conversion factor and recovery rate of 12.5% which probably overestimates the green weight equivalent. *, split by area not available; –, no catch limits set, or no reported catch (for Spirits Bay). Data for 1999 are provisional and approximate.**

	Catch limits (t)		Landed catch (t)		Estimated catch (t, green)		
Season	Meat	Approx. green	Meat	Green	Whangarei	Far North	Spirits Bay
1980	–	–	–	238	*	*	*
1981	–	–	–	560	*	*	*
1982	–	–	–	790	*	*	*
1983	–	–	–	1 171	78	1 093	–
1984	–	–	–	541	183	358	–
1985	–	–	–	343	214	129	–
1986	–	–	–	675	583	92	–
1987	–	–	–	1 625	985	640	–
1988	–	–	–	1 121	1 071	50	–
1989	–	–	–	781	131	650	–
1990	–	–	–	519	341	178	–
1991	–	–	–	854	599	255	–
1992	–	–	–	741	447	294	–
1993	–	–	–	862	75	787	1
1994	–	–	–	1 634	429	1 064	142
1995	–	–	214	1 469	160	810	499
1996	189	1 508	132	954	55	387	512
1997	189	1 508	126	877	22	378	477
1998	98	785	31	233	0	102	130
1999	98	785	18	132	0	109	23

Table 2: **Catch limits and landings (t greenweight or meatweight) from the Coromandel fishery since 1980. "Landed" figures come from the landed section of the Catch Effort and Landing (CELR) form and "Estimated" figures from the effort section and are pro-rated to sum to the total landed greenweight. "Hauraki" includes areas 2X and 2W, "Whitianga" includes 2L and 2K, "Barrier " includes 2R, 2S, and 2Q, "Bay of Plenty" includes areas 2A–2I. Catch limits since 1992 specified on permits in meatweight. "Approximate greenweight" assumes the gazetted conversion factor of 12.5% and probably overestimates the real greenweight. * Landings in 1991 include about 400 t from Colville; –, no catch limits set. Data for 1999 are provisional and approximate.**

	Catch limits		Landed		Estimated			
Season	Meat	Approximate greenweight	Meat	Green	Hauraki Gulf	Whitianga	Barrier Islands	Bay of 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	–	–	–	1005	249	690	23	77
1981	–	–	–	1170	332	743	41	72
1982	–	–	–	1050	687	385	49	80
1983	–	–	–	1553	687	715	120	31
1984	–	–	–	1123	524	525	62	12
1985	–	–	–	877	518	277	82	0
1986	–	–	–	1035	135	576	305	19
1987	–	–	–	1431	676	556	136	62
1988	–	–	–	1167	19	911	234	3
1989	–	–	–	360	24	253	95	1
1990	–	–	–	903	98	691	114	0
1991	–	–	–	1392	*472	822	98	0
1992	154	1232	–	901	67	686	68	76
1993	132	1056	–	455	11	229	60	149
1994	66	528	–	323	17	139	48	119
1995	86	686	79	574	25	323	176	50
1996	88	704	80	594	25	359	193	18
1997	105	840	89	679	26	473	165	15
1998	110	880	19	204	1	199	2	1
1999	29	230	7	47	0	12	17	18

3. RESEARCH

3.1 Stock structure

Little is known of the stock structure of New Zealand scallops. It is currently assumed for management that the Coromandel fishery is separate from the adjacent Northland fishery and from the various west coast harbours, Golden Bay, Tasman Bay, Marlborough Sounds, Stewart Island, and Chatham Island fisheries.

3.2 Resource surveys

Scaled length frequency distributions from major areas of the Northland and Coromandel fisheries since 1993 are shown in Figures 2–5. The fraction of scallops above the MLS of 100 or 90 mm varies considerably from bed to bed and abundance in most beds varies considerably among years. Full details of the dredge surveys conducted in April–May 2001 which led to these data were given by Cryer & Parkinson (2002).

3.3 Other studies

Walshe (1984) estimated the parameters of the von Bertalanffy growth function for scallops in Bay of Plenty and Hauraki Gulf beds using Gulland's (1964) method of analysing tag return data. He found both K and L_∞ to be different for these two areas (1.20 *vs.* 0.38 y^{-1} and 116 *vs.* 141 mm, respectively). Walshe's estimates have been used for many years to estimate the expected growth of scallops between the midpoint of surveys and the start of the season. Both growth curves derived by Walshe suggest that scallops of 95 mm length or greater are likely to grow to the legal size of 100 mm during the period between survey and season, and 95 mm has therefore been used as a "critical size" to divide scallops likely to recruit from those unlikely to recruit by the start of each season. Analysis of L.G. Allen's (unpublished) data by Cryer & Parkinson (1999b) suggested that the growth rate of scallops close to 100 mm long was variable between years and with depth. This could render start-of-season biomass estimates sensitive to growth rate between survey and season and to the depth distribution of scallop biomass. The implications of these results have not been examined in detail, so it is assumed for the purpose of predicting start-of-season biomass that scallops of 95 mm or over at the time of the survey are likely to grow to 100 mm by the start of the season, and that scallops of 85 mm or over at the time of the survey are likely to grow to 90 mm by the start of the season. Until 1997, start-of-season biomass of 100 mm scallops was used to estimate yield for both fisheries (notwithstanding the lower MLS in the Coromandel fishery). CAY estimators, using the predicted start-of-season biomass at the appropriate MLS, have been used since.

Cryer (2001a) summarised estimates of the natural mortality rate of scallops in the Coromandel fishery. The various experiments generated estimates of M with an average of about 0.47 y^{-1} but, because some experiments used enclosures and are likely to have underestimated M, Cryer (2001a) suggested the adoption of a value of 0.50 y^{-1} for biomass and yield estimates.

3.4 Biomass estimates

Composite dive-dredge surveys were used throughout the Northland fishery between 1992 and 1997, except in 1993 when only divers were used (Table 3). Diver surveys of the Whitianga beds were carried out almost annually between 1978 and 1997 (Table 4), and composite dive-dredge surveys covering most commercially exploited beds in the Coromandel fishery were conducted annually between 1992 and 1997. All diving was discontinued in 1998 in favour of (cheaper) dredge-only surveys. The Northland fishery was not surveyed in 1999 or 2000, and the Coromandel fishery was not surveyed in 2000. Dredge surveys of both fisheries were conducted in 2001 and these were described by Cryer & Parkinson (2002). Where dredges have been used, absolute biomass must be estimated using multipliers to correct for the efficiency of the particular dredges used. Previously, these multipliers were estimated by comparing dredge counts with diver counts in experimental areas (e.g., Cryer & Parkinson 1999). However, different vessels were used in 2001 and no trials were conducted into the efficiency of the dredges used. Both 2001 surveys were therefore corrected using a precautionary interpretation of historical dredge efficiency estimates (Cryer & Parkinson 2002).

The 2001 biomass estimates for the Northland fishery in Table 3 were calculated using historical average dredge efficiency. This is not the same as the more precautionary approach used to estimate biomass for the purpose of yield calculations. However, they show that biomass in Spirits Bay and Rangaunu Bay was similar in 2001 to the previous survey in 1998. The beds at Stevenson's Island (Whangaroa) and Doubtless Bay both had their lowest ever estimates of recruited biomass, even using historical average dredge efficiency, and they are unlikely to contribute to the fishery in 2001. The bed at Bream Bay seems to have improved from a nadir in 1998 (the 1997 estimate of 580 t for Bream Bay is based on very few samples and is probably unreliable). Beds at Great Exhibition Bay, through the Cavalli Passage, and at Mangawhai and Pakiri Beach were not surveyed but were expected by fishers not to be productive in 2001.

Table 3: **Estimated recruited biomass of scallops (at the time of surveys) in various component beds of the Northland scallop fishery since 1992, assuming historical average dredge efficiency of 63.7%. – indicates no survey in a given year. Estimates of biomass given for 1993 are probably negatively biased, especially for Rangaunu Bay (*), by the restriction of diving to depths under 30 m, and all estimates before 1996 are negatively biased by the lack of surveys in Spirits Bay (†). Totals also include biomass from less important beds at Mangawhai, Pakiri, around the Cavalli Passage, in Great Exhibition Bay, and Tom Bowling Bay when these were surveyed. Commercial landings in each year for comparison can be seen in Table 1, wherein "Far North" landings come from beds described here as "Whangaroa", "Doubtless" and "Rangaunu"**

						Biomass (t)
Year	Bream Bay	Whangaroa	Doubtless	Rangaunu	Spirits Bay	Total
1992	1 733	–	78	766	–	†3 092
1993	569	172	77	*170	–	*1 094
1994	428	66	133	871	–	†1 611
1995	363	239	103	941	–	†1 984
1996	239	128	32	870	3 361	5 098
1997	580	117	50	1 038	1 513	3 974
1998	18	45	37	852	608	1 654
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	112	7	0	721	606	1 446

The beds at the Mercury islands, close to Whitianga, has been one of the mainstays of the Coromandel fishery since the fishery began. Biomass has varied by about an order of magnitude, with seemingly little link to fishing pressure (e.g., Cryer 1994). However, the two most recent biomass estimates have been the worst on record, and eight of the ten lowest estimates in the history of the fishery have been since 1993, Table 4). Historically, the second most important bed in the Coromandel fishery was at Waiheke. This bed underwent a rapid decline in the late 1980s and was essentially unfished between 1993 and 1996. Following very low estimates in 1994 to 1996, the biomass at Waiheke appeared to increase in 1997 and 1998, but was very low in 1999. Despite the presence of very large numbers of scallops in 2001, the recruited biomass was again low because most of the scallops were small. The bed at Little Barrier Island was highly productive in the mid 1990s, but surveys in 1998 and 1999 showed relatively low populations, and the 1999 biomass was the smallest on record. The 2001 biomass was much higher than in 1998 and 1999, but not as high as between 1996 and 1998.

Table 4: Estimated recruited biomass (at the time of surveys) of scallops of 95 mm or greater shell length in various component beds of the Coromandel scallop fishery since 1978 using historical average dredge efficiency. – indicates no survey in a given year, * not all beds surveyed, estimate of total biomass probably significantly biased low. Commercial landings in each year for comparison are given in Table 1, wherein "Bay of Plenty" landings come from beds described here as "Waihi" and "Motiti".

						Biomass (t)
Year	Waiheke	Whitianga	L. Barrier	Waihi	Motiti	Total
1978	–	1 386	–	–	–	–
1979	–	368	–	–	–	–
1980	–	1 197	–	–	–	–
1981	–	1 092	–	–	–	–
1982	–	725	–	–	–	–
1983	–	998	–	–	–	–
1984	800	1 092	–	–	–	*1 892
1985	2 000	966	–	–	–	*2 966
1986	1 500	1 313	–	–	–	*2 813
1987	–	1 628	–	–	–	–
1988	–	–	–	–	–	–
1989	–	–	–	–	–	–
1990	608	767	–	–	–	*1 375
1991	266	824	–	–	–	*1 090
1992	73	1 272	–	–	–	*1 345
1993	41	748	–	735	–	*1 524
1994	3	481	–	153	–	*637
1995	26	445	258	58	451	1 277
1996	28	619	346	19	222	1 244
1997	508	623	402	70	199	1 839
1998	506	641	99	12	120	1 414
1999	18	176	19	0	87	325
2000	–	–	–	–	–	–
2001	19	142	152	–	70	403

3.5 Yield estimates

3.5.1 Estimation of Maximum Constant Yield (MCY)

MCY is not normally estimated for scallops and, given the highly variable nature of most wild scallop fisheries, is likely to be close to zero.

3.5.2 Estimation of Current Annual Yield (CAY)

The choice among reference mortality rates for estimating yield is not a simple one. It is probably useful to use Caddy's (1998) notation of target reference points (TRP) and limit reference points (LRP) where reference points can be measures of fishing mortality (F) or biomass (B). F_{max} from a yield-per-recruit model was the classical TRP (Caddy 1998), but may be too high as a target (Annala *et al.* 2000) and has more recently been generally regarded as an LRP (a "threshold" beyond which fishing mortality should not be increased) and $F_{0.1}$ has been substituted as a "target" (Caddy 1998). Mace (1994) recommended $F_{40\%}$ as a "default" TRP in the "common situation where there is adequate information to place bounds on all relevant life history parameters except those characterising the stock-recruit relationship" (although Collie & Gislason, 2001, list $F_{40\%}$ as a LRP). Mace's (1994) simulations showed that, in her model, $F_{40\%}$ was similar to $F_{0.1}$ when recruitment and maturity schedules coincided, and approximated F_{MSY} for fisheries of average to high resilience to fishing. She also affirmed Mace & Sissenwine's (1993) proposition that the default overfishing threshold should be 20% B_0 for stocks of at least average resilience to fishing. However, Myers et al. (1994) considered this threshold (20% of virgin stock size) the least desirable and the least precautionary of those they examined. The available information and models allowed the estimation of F_{max} as a LRP, and $F_{0.1}$ and $F_{40\%}$ as TRPs in 2001.

Cryer & Morrison (1997) modelled yield-per-recruit in the Coromandel fishery, but their model was modified to incorporate growth parameters more suited to the Northland fishery and used to estimate reference fishing mortality rates for that fishery. For an assumed rate of natural mortality of M = 0.50 y^{-1}, $F_{0.1}$ was estimated as 0.550 y^{-1}, and F_{max} as 0.700 y^{-1}. $F_{40\%}$ was not estimated. Yield estimates based on $F_{0.1}$ should probably be preferred as targets over that based on F_{max} (which might be considered a limit). The following modified version of the Baranov equation given by Cryer & Morrison (1997) should be used in their application.

$$CAY = \frac{F_{ref}}{F_{ref} + \frac{7M}{12}} * \left[1 - e^{-\left(F_{ref} + 7M/12\right)}\right] * B_{jul} \qquad (1)$$

where B_{jul} is the estimate of recruited biomass in July. Natural mortality is assumed to act in tandem with fishing mortality for the first 7 months of the year, the length of the current Northland commercial scallop season.

The recruited biomass of scallops 100 mm in shell length or greater in the Northland fishery was estimated by Cryer & Parkinson (2001) to be 1010 t green weight in 2001. CAY was calculated using this biomass and the reference fishing mortality rates $F_{0.1}$ and F_{max} as follows (the conversion rate from green weight to meat was assumed to be 13.5%, Cryer & Parkinson 1999):

For $F_{0.1}$, CAY = 0.6535 * 0.690 * 871 = 323 t (green) or 44 t (meat)

For F_{max}, CAY = 0.7059 * 0.6290 * 871 = 387 t (green) or 52 t (meat)

These estimates of CAY would have a *c.v.* at least as large as the estimate of start of season recruited biomass (27%) and relate to the surveyed beds only. The level of risk to the putative Northland scallop stock of fishing at the estimated CAY level cannot be determined.

Cryer & Morrison's (1997) estimates of $F_{40\%}$ (0.514 y^{-1}), $F_{0.1}$ (0.508 y^{-1}), and F_{max} (0.650 y^{-1}) (all assuming M = 0.50 y^{-1}) were used to estimate yield as CAY. Yield estimates based on $F_{40\%}$ and $F_{0.1}$ should probably be preferred as targets over that based on F_{max} (which might be considered a limit). Because of the derivation of these estimates, they should be applied to the modified version of the Baranov equation given by Cryer & Morrison

$$CAY = \frac{F_{ref}}{F_{ref} + \frac{5M}{12}} * \left[1 - e^{-\left(F_{ref} + 5M/12\right)}\right] * B_{jul} \qquad (2)$$

where B_{jul} is the estimate of recruited biomass in July. In this formulation of the Baranov equation, natural mortality is assumed to act in tandem with fishing mortality for the first 5 months of the year, the length of the current Coromandel commercial scallop season.

The recruited biomass of scallops 90 mm in shell length or greater in the Coromandel fishery was estimated by Cryer & Parkinson (2001) to be 577 t greenweight in 2001. CAY was calculated using this biomass and each of the reference fishing mortality rates $F_{0.1}$, F_{max}, and $F_{40\%}$ as follows (the conversion rate from greenweight to meat was assumed to be 13.5% (Cryer & Parkinson 1999a)):

For $F_{40\%}$, CAY = 0.7116 * 0.5144 * 577 = 211 t (green) or 28 t (meat)

For $F_{0.1}$, CAY = 0.7092 * 0.5115 * 577 = 209 t (green) or 28 t (meat)

For F_{max}, CAY = 0.7573 * 0.5761 * 577 = 252 t (green) or 34 t (meat)

These estimates of CAY would have a *c.v.* at least as large as that of the estimate of start-of-season recruited biomass (27%), and relate to the surveyed beds only. The level of risk to the putative Coromandel scallop stock of fishing at the estimated CAY level cannot be determined.

3.5.3 Estimation of Provisional Yield

Provisional Yield (PY) (Cryer 1994) is estimated as the lower limit of a 95% confidence distribution for the estimate of start-of-season recruited biomass, plus an amount to account for beds not surveyed before the season. The amount added for un-surveyed beds is estimated as the product of the variability factor (Annala *et al.* 2000; M > 0.35, c = 0.6 for scallops) and the historical average landings from the unsurveyed beds. PY is estimated only for comparison with historical estimates of yield.

For Coromandel scallops in 2001 (Cryer & Parkinson 2001), start-of-season recruited biomass (100 mm or greater) was estimated at 195 t (greenweight) with a *c.v.* of 29%, giving a lower tail to the 95% confidence distribution of 82 t. Beds not included in the surveys were excluded specifically because they were thought unlikely to support commercial fishing in 2001, so no addition for un-surveyed beds was made:

PY = 82 t + 0.6 * 0 t = 82 t (greenweight) or 11 t (meat)

The level of risk to the putative Coromandel scallop stock of fishing at the estimated PY level cannot be determined.

3.5.4 Estimation of yield using in-season "depletion analysis"

Cryer (2001b) examined the proposition that in-season analysis of catch and effort data could be used to estimate biomass and yield. Despite the availability of full and extensively groomed catch and effort data, however, depletion analysis generated statistically significant regression coefficients (from which biomass is estimated) in only four out of eight years for the two main beds (at Whitianga and Little Barrier Island), and these estimates were not correlated with preseason survey estimates. Cryer (2001b) therefore considered depletion analysis unsuitable as a means of estimating biomass or yield in the Coromandel fishery. There is no reason to suppose this approach would be more appropriate for the Northland fishery.

3.6 Models

Yield- and egg-per-recruit models were developed for Coromandel commercial dredge fisheries for scallops by Cryer & Morrison (1997). This modelling, incorporating the incidental effects of dredging on the growth and mortality rates of scallops, allowed the application of reference fishing mortality rates $F_{0.1}$, F_{max}, and $F_{40\%}$ for the first time in 1998 (see also Cryer 1998 for the Northland fishery).

4. Management implications

The 1999 biomass was, for poorly understood reasons, the lowest ever recorded in the Coromandel fishery. There was no survey in Northland in that year, but fishing was, anecdotally, poor. There were no surveys in 2000. There have been large fluctuations in biomass in the past 20 years, and years of low biomass have sometimes been followed by years of high biomass. However, both fisheries were poor in 2000, and the 2001 biomass estimates give cause for only cautious optimism. Based on analysis of catch and effort data, Cryer (2001b) suggested that high mortality occurred between survey and season in 1998 in the Coromandel fishery, and may have occurred in the Northland fishery too and continued since. The cause of this mortality is not known, but an associated and very visible "black gill" condition was reported in several species of filter feeding bivalves around the Coromandel Peninsula in 1999 (Diggles et al. 2000). Diggles concluded that the black gill condition was probably not indicative of a causative disease agent (although Rickettsiales like organisms were found in animals with the condition), and suggested that broad scale environmental conditions were probably responsible in some way.

Whatever the cause of any high mortality in 1998 and 1999, both fisheries still appear to be "depressed" in 2001, and this suggests that caution should be exercised when setting catch limits. The lack of strong correlation between biomass and fleet average catch rate in the Whitianga bed (Cryer 2001b) suggests that it may be possible for fishers to catch or kill a large proportion of scallops 90 mm shell length or larger before the fishery becomes uneconomic. The consequences of such a depression in recruited and spawning biomass are not known as the current commercial MLS of 90 mm has been in force in the Coromandel fishery only since 1995. Maturation of scallops at 60 mm shell length, well below the MLS, does not appear to protect this stock from serious depression of spawning biomass, probably because small scallops carry few eggs compared with larger individuals. Stochastic egg-per-recruit (EPR) modelling (Cryer & Morrison 1997) suggested that, assuming knife edge recruitment at 90 mm, fishing at $F_{0.1}$ or F_{max} would reduce the lifetime fecundity of a cohort to about 33–40% of its virgin level. Population fecundity in a given year would be reduced to the same level under constant recruitment. EPR modelling (Cryer & Morrison 1997) suggested that unrestrained fishing mortality could reduce population fecundity to less than 15% of its virgin level under constant recruitment, especially if there were large incidental effects on small but mature scallops of 60–90 mm shell length. The recent series of low biomass years in the Coromandel fishery (evidence is scarcer for the Northland fishery) suggest that recent average recruitment has been low, and equilibrium estimates of population fecundity relative to virgin levels are likely to be optimistic. Thus, under the 90 mm MLS, failure to restrain fishing mortality could result in depression of the effective spawning stock size below 15% of the unfished level. Although recruitment over-fishing is rarely considered a serious issue for bivalve molluscs (e.g., Hancock 1973), relationships between stock size and subsequent recruitment have been published for scallops and other invertebrates (e.g., scallops Peterson & Summerson 1992, Peterson et al. 1996; sea urchins, Quinn et al. 1993, Pfister & Bradbury 1996; abalone, Prince et al. 1988, Tegner 193; clams, Peterson 2002; and whelks, Stoner & Ray-Culp 2000). There is, therefore, accumulating evidence that recruitment in highly fecund invertebrate species may be influenced by stock size under some circumstances, and it would be prudent to restrain fishing mortality below F_{max} as a precaution against recruitment over-fishing. Full stochastic population modelling would be useful to examine the possible effects of variable recruitment and growth on the estimates of reference fishing mortality given for this stock by Cryer & Morrison (1997).

5. ACKNOWLEDGMENTS

This work was funded by the Ministry of Fisheries under contracts SCA2000/01 and SCA2000/02. Thanks to skippers and crew on board dredge boats for their assistance. Members of the Shellfish Fishery Assessment Working Group reviewed an early draft and made several suggestions for improvement. Dave Gilbert's review was much appreciated, especially for his remarkable attention to detail.

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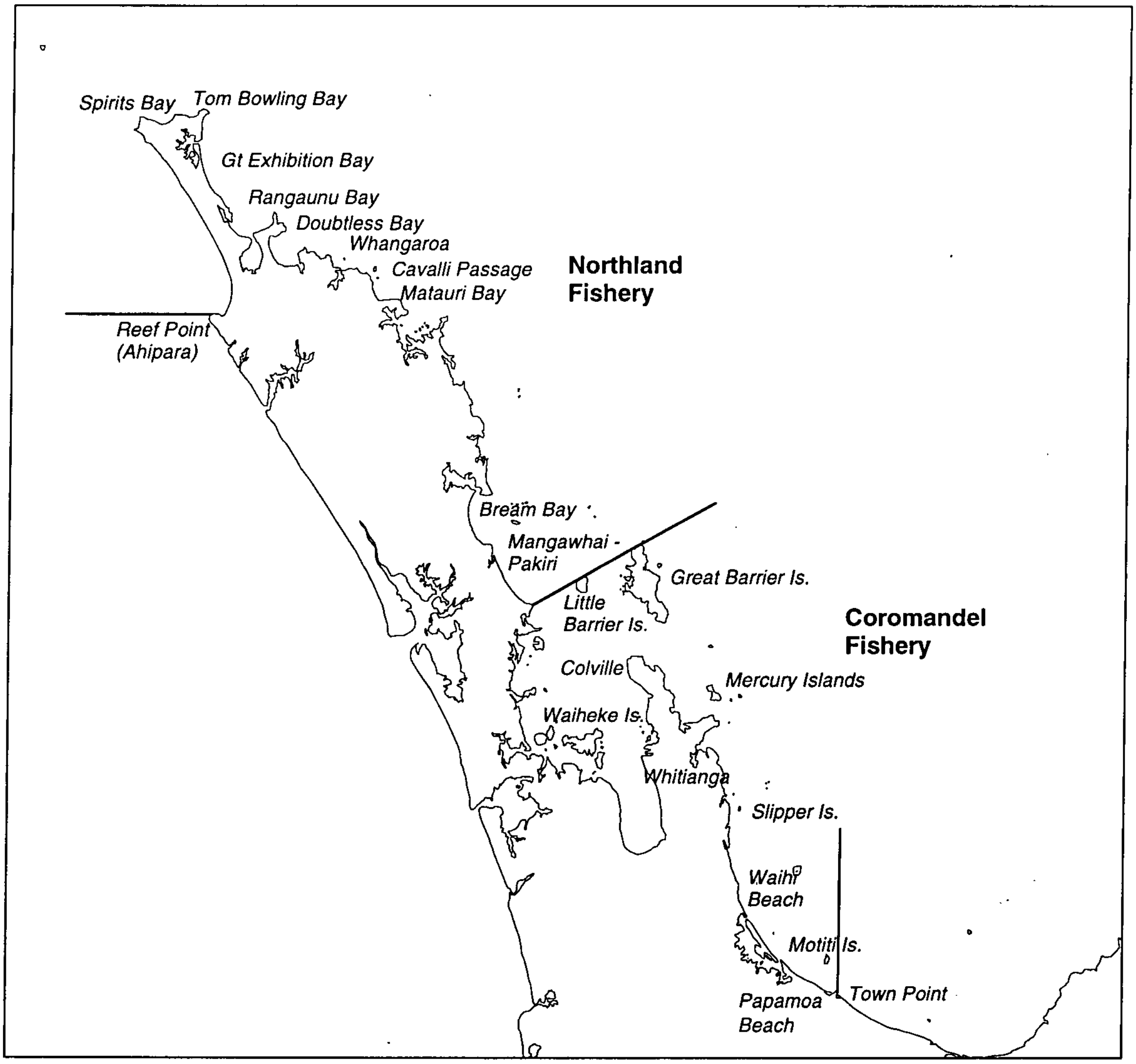

Figure 1: **Geographic distribution of the two northern scallops fisheries and the names of locations mentioned in the text.**

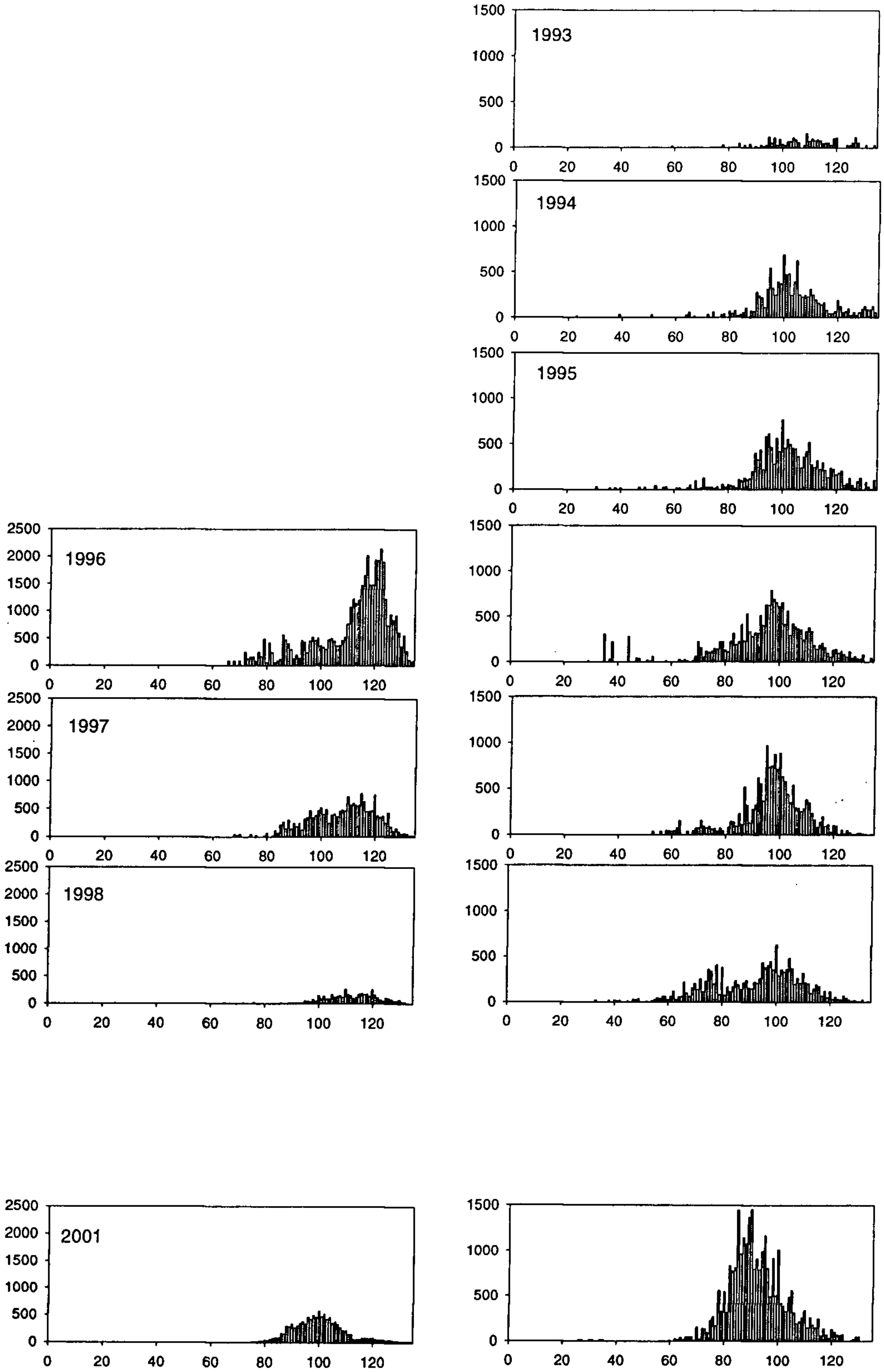

***Figure 2*: Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Spirits Bay and Tom Bowling Bay; right panel, Rangaunu Bay and Doubtless Bay. There were no surveys in Spirits Bay or Tom Bowling Bay before 1996.**

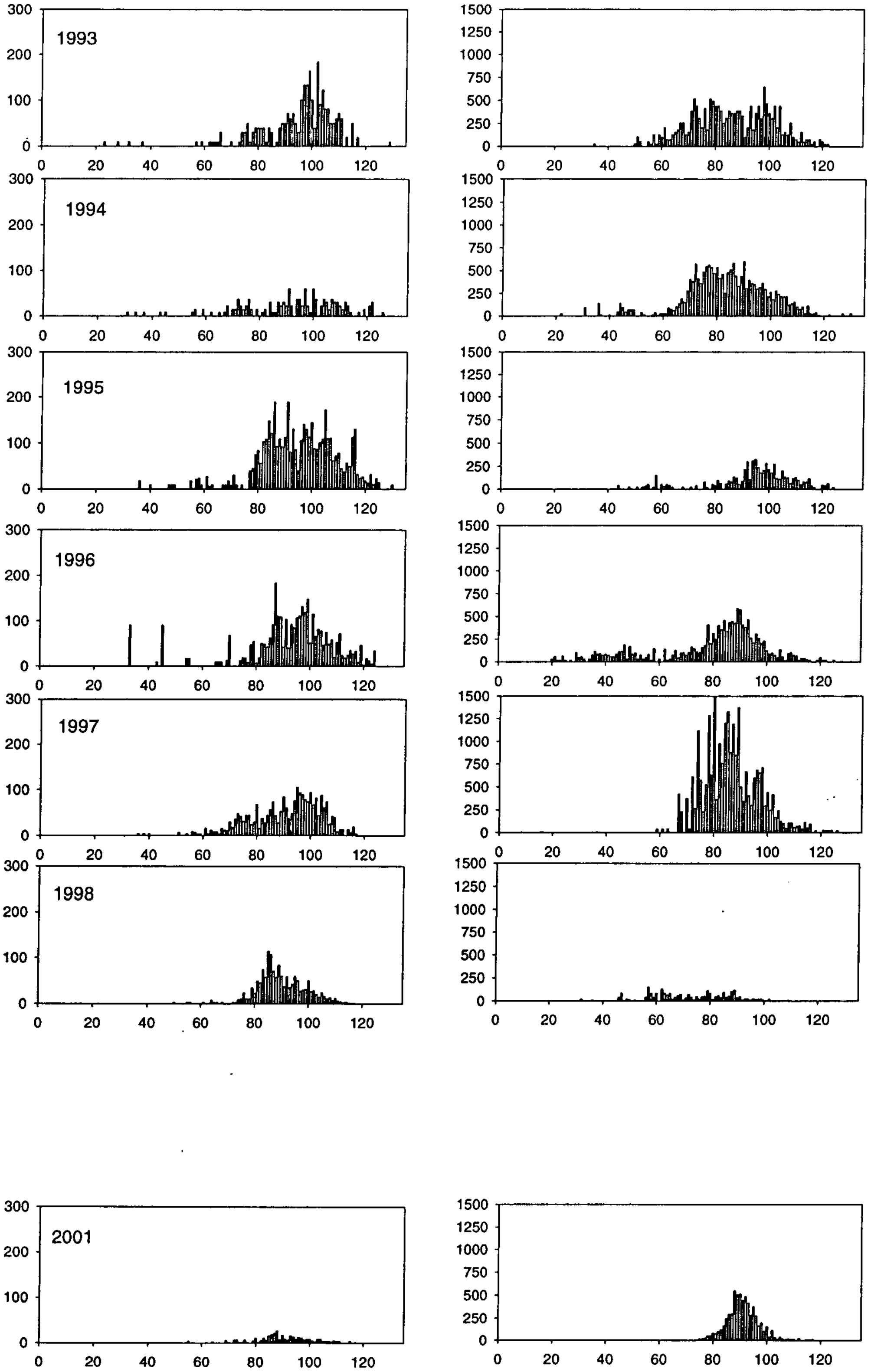

***Figure 3*: Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Stevenson's Island (Whangaroa); right panel, Bream Bay. The 1997 result for Bream Bay was based on very few samples and may be unreliable.**

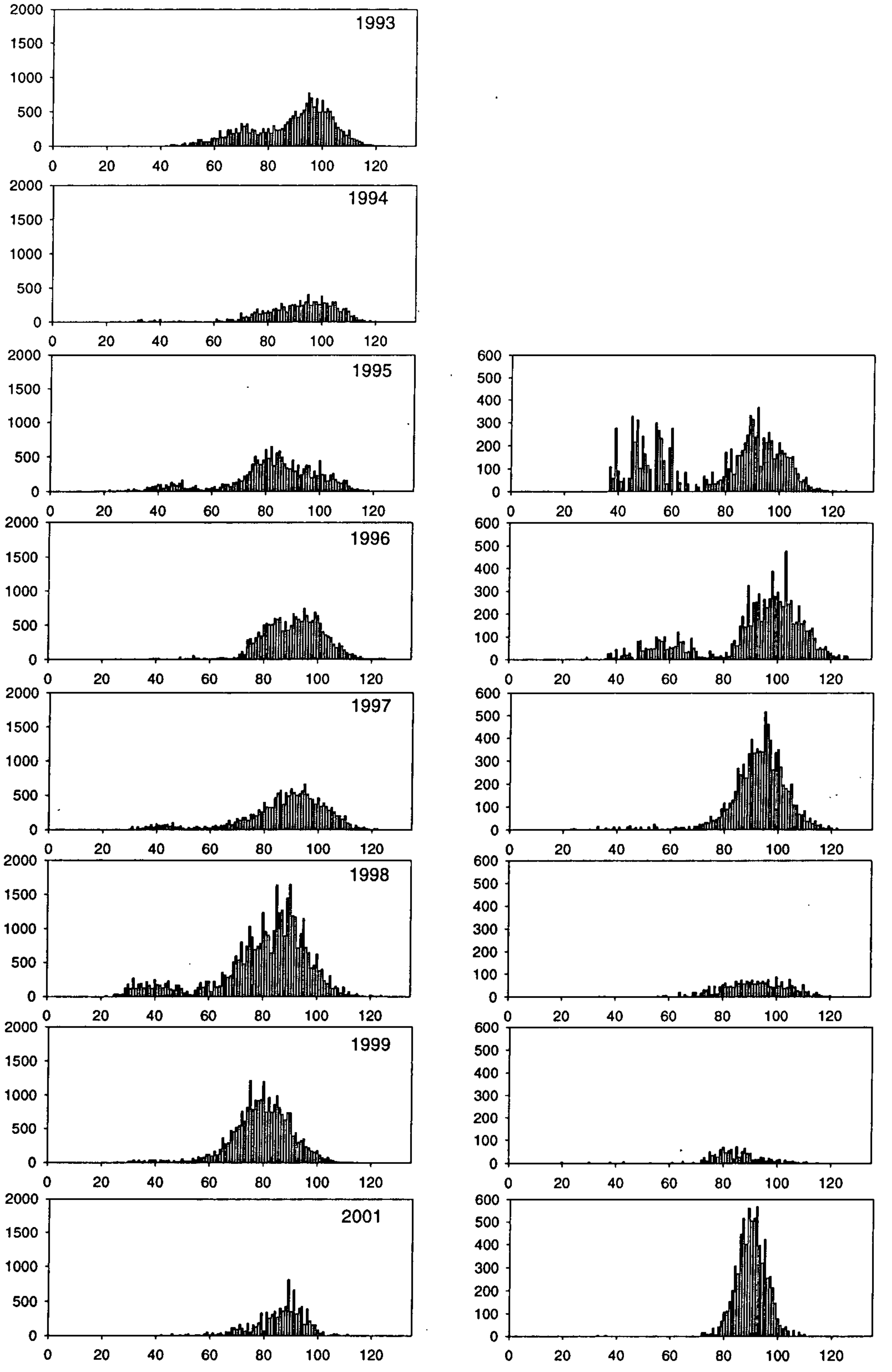

***Figure 4*: Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Mercury Islands; right panel, Little Barrier Island. There were no surveys at Little Barrier Island before 1995.**

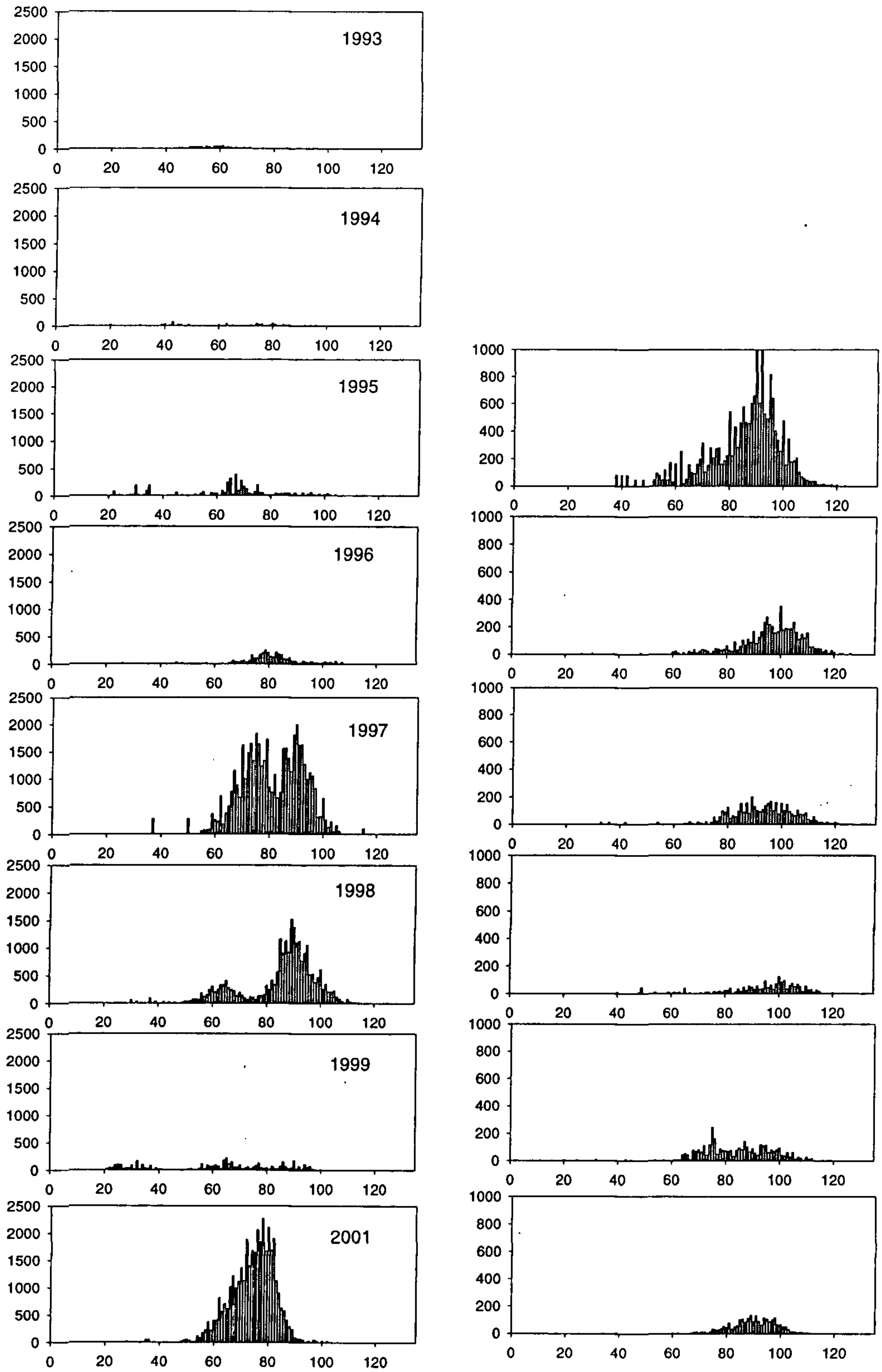

***Figure 5*: Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected using historical average dredge efficiency by size class. Left panel, Waiheke Island; right panel, Motiti and Papamoa Beach. There were no surveys at Motiti–Papamoa before 1995.**

Dredge surveys of scallops in the Northland and Coromandel scallop fisheries, 2001

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NIWA Technical Report No. xx
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Contents

Abstract

Dredge surveys of scallops in the Northland and Coromandel scallop fisheries, 2001. *NIWA Technical Report xx. 24 p.*

Dredge surveys for scallops were carried out in the Northland and Coromandel fisheries in April–May 2001. Many strata and parts of strata thought by fishers unlikely to support commercial fishing in 2001 and all areas closed to commercial fishing were excluded. Biomass estimates made by the area swept method were corrected using precautious interpretations of historical data on dredge efficiency and are considered to be estimates of absolute biomass. Start-of-season biomass was predicted for each fishery by assuming seasonally constant mortality and growth. For the Northland fishery, absolute start-of-season biomass over 100 mm shell length was predicted to be 871 t greenweight (118 t meatweight) with a standard error of about 27% (estimated by simulation). For the Coromandel fishery, absolute start-of-season biomass over 100 mm shell length (for comparison with previous surveys) was predicted to be 195 t greenweight (26 t meatweight) with a standard error of about 29% (estimated by simulation). This is the second lowest estimate since surveys began in 1978, but is a slight improvement on 1999 survey results. Including all scallops likely to be over the commercial minimum legal size of 90 mm by the start of the season increased this estimate to 577 t greenweight (78 t meatweight) with standard errors of about 27% of the mean. Estimated standard errors for the 2001 surveys are wider than for most recent surveys because of uncertainty about dredge efficiency.

Introduction

This report describes dredge surveys for scallops (*Pecten novaezelandiae*) carried out under contract to the Ministry of Fisheries (projects SCA2000/02 and SCA2000/01 for the Northland and Coromandel fisheries, respectively). Surveys in the Northland fishery were conducted annually between 1992 and 1998, with increasing coverage of the fishery each year. Surveys were conducted in the Coromandel fishery almost annually between 1978 and 1999, again with coverage of the fishery increasing with time. In both fisheries, survey designs were refined over the years using historical survey data, catch-effort information, a review of optimisation procedures, and discussions with managers and fishers. There was no survey in the Northland fishery in 1999, and no survey in either fishery in 2000.

Between 1992 and 1994, survey results were used to estimate Provisional Yield (PY, after a method by Cryer, 1994) and set catch limits for the Coromandel fishery and, to a lesser extent, the Northland fishery. The minimum legal size (MLS) for scallops taken commercially in the Coromandel fishery was reduced from 100 to 90 mm at the start of the 1995 season. The MLS remained at 100 mm in the Northland fishery and for all amateur fishers. The management plan for the Coromandel fishery (for 1995 to 1997 seasons) adopted an assessment regime whereby the available yield was still calculated using Provisional Yield (PY) based on the abundance and biomass of scallops greater than 100 mm shell length, pending research into more appropriate methods. This research was completed in late 1997 when the management plan expired. A more typical "Current Annual Yield" (CAY) yield estimator was adopted in 1998, based on predicted start-of-season recruited biomass and estimates of reference fishing mortality incorporating incidental effects of the dredge method on scallop growth and mortality (Cryer & Morrison 1997).

For poorly understood reasons, biomass and catches from both scallop fisheries have been very low since about 1998 (Cryer 2001a). In the Coromandel fishery, low biomass has coincided with poor condition, "black gill" syndrome (Diggles et al. 2000), and a rapid increase (since 1996) of the filter-feeding tubeworm *Chaetopterus* sp. on many of the beds. *Chaetopterus* sp. builds large clumps of parchment-like tubes and renders dredging for scallops impossible (because the dredge fills with tubes and therefore cannot catch scallops). There may have been catastrophic mortality of scallops on some beds (Cryer 2001b), but the role played by the expansion of *Chaetopterus* sp. is not known, despite anecdotal reports that scallops do not survive where *Chaetopterus* sp. is abundant. The causes of these apparently major changes to the ecology of the Coromandel fishery are far from clear, but broadly parallel trends in biomass in the Northland fishery suggest that they act on a very broad scale.

The principal aim of the 2001 survey work was to estimate the absolute abundance of scallops by size class on those beds of the Northland and Coromandel fisheries likely to support successful commercial fishing in the 2001 season. Recruited biomass at the start of the forthcoming season (15 July of each year) can then be predicted in greenweight and meatweight using information on growth, mortality, and likely condition during the season. Estimates of yield based on the biomass estimates are derived in a separate document.

Objectives

Surveys were designed to achieve the following objective specified in the contract with the Ministry of Fisheries (for either the Northland or Coromandel fishery):

1. To estimate the absolute abundance and population size frequency of scallops in the main scallop beds by 1 May 2001. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance is 20%.

Methods

Survey timing

Surveys were conducted in April and early May 2001, after several delays caused by inclement weather. The choice of an appropriate time for surveys entails balancing the conflicting pressures of operational ease and uncertainty in the results. Early surveys benefit from long daylight hours and settled weather, but the long lag between survey completion and season opening render biomass estimates sensitive to the assumed values for growth and mortality. In addition, scallops are susceptible to periodic catastrophic declines in abundance, and a longer lag between survey and season increases the probability of such an occurrence. Surveys undertaken later in the year can be hampered by short working days and less favourable conditions, and the danger of surveys being seriously delayed by inclement weather increases. However, the impact on biomass estimates of poor assumptions about growth and mortality is smaller, and the chance of catastrophic declines in abundance following the survey is reduced.

Survey design

All sampling for the 2001 surveys was, in accordance with requests from the Ministry of Fisheries, undertaken by dredge. No diving to estimate dredge efficiency was done pending a review of historical data (to be undertaken as part of the same projects but after the biomass surveys).

For the Northland fishery, single phase stratified random sampling was undertaken in 10 strata: Spirits Bay and Tom Bowling Bay (three strata), Rangaunu Bay (three strata), Doubtless Bay (two strata), Stevensons Island (one stratum), and Bream Bay (one stratum). After excluding strata thought unlikely to be productive in 2001 and areas closed to commercial fishing, the total sampled area in 2001 was only 403 km^2 (compared with 553–714 km^2 in 1996–98, Figure 1; Appendix 1).

For the Coromandel fishery, single phase stratified random sampling was undertaken in 12 strata: Waiheke Island (one stratum), Kawau Island (one stratum), Little Barrier Island (two strata), Great Barrier Island (one stratum), Mercury Islands (five strata), and Motiti Island to Papamoa (two strata). After excluding strata thought unlikely to be productive in 2001 and areas closed to commercial fishing, the total sampled area in 2001 was only 125 km^2 (compared with 253–341 km^2 in 1996–99, Figure 2; Appendix 2).

Allocation of stations to strata and site selection

Surveys were not formally optimised to minimise the predicted *c.v.* of the estimate of recruited biomass for three reasons. First, no surveys were conducted in 2000 (or 1999 in Northland), so there was no recent information upon which to base the statistical optimisation procedures developed by Cryer & Parkinson (1999). Second, many strata were radically redesigned for 2001 surveys in response to major changes in the fishery performance and, for the Coromandel fishery, invasive *Chaetopterus* tubeworms that preclude survey by dredge. Third, time constraints on the surveys limited the number of ways in which stations could be allocated to strata. These constraints necessitated a more pragmatic approach than has been used in the past (e.g., Cryer & Parkinson 1999). Strata that were sufficiently close together to tackle in a single day (e.g., those in Rangaunu Bay in the Northland fishery or those at the Mercury Islands in the Coromandel fishery) were grouped. Up to about 25 shots can be completed in a problem-free day with little steaming, so stations were allocated to strata within groups according to their relative stratum sizes and a qualitative understanding of historical performance until the total for the group was 20–25.

The positions of stations within strata were randomised using the Random Stations package (RAND_STN v 1.7 for PCs; MAF Fisheries 1990) constrained to keep all stations at least 500 m apart. This package estimates the area of each stratum, and gives the latitude and longitude of each random station.

Vessels and gear: dredge sampling

Dredging was undertaken from the chartered commercial dredge vessels *Sheba* (in the Northland fishery) and *San Tam* (in the Coromandel fishery); in both cases, different vessels and skippers were used in 2001 than between 1995 and 1999. The skipper's brief was to tune his gear (select course, speed, warp length, etc.) so as to maximise his total catch at that station. Tows were nominally 0.3 – 0.5 nautical miles (556–926 m, assessed using non-differential GPS), depending on the expected average size of the catch. However, the dredge occasionally lost contact with the bottom or "flew" (because of hard or uneven substrates, an increase in depth, a dredge full of detritus or scallops, etc.) and, on these occasions, the tow was terminated and the actual distance travelled along the ground was estimated using GPS. At the end of each tow, the dredge was retrieved and emptied onto the sorting tray on the boat. All live scallops were separated from the detritus and bycatch and their maximum lengths measured to the nearest millimetre rounded down. Occasionally, large catches were randomly subsampled for length. Unmeasured scallops were counted unless the catch was very large indeed; in these instances, the catch was distributed among two or more identical fish bins filled to indistinguishable levels, and one bin was selected at random for enumeration and random subsampling for measurement. No facilities for weighing the catch at each station were available to estimate the fraction sampled by weight.

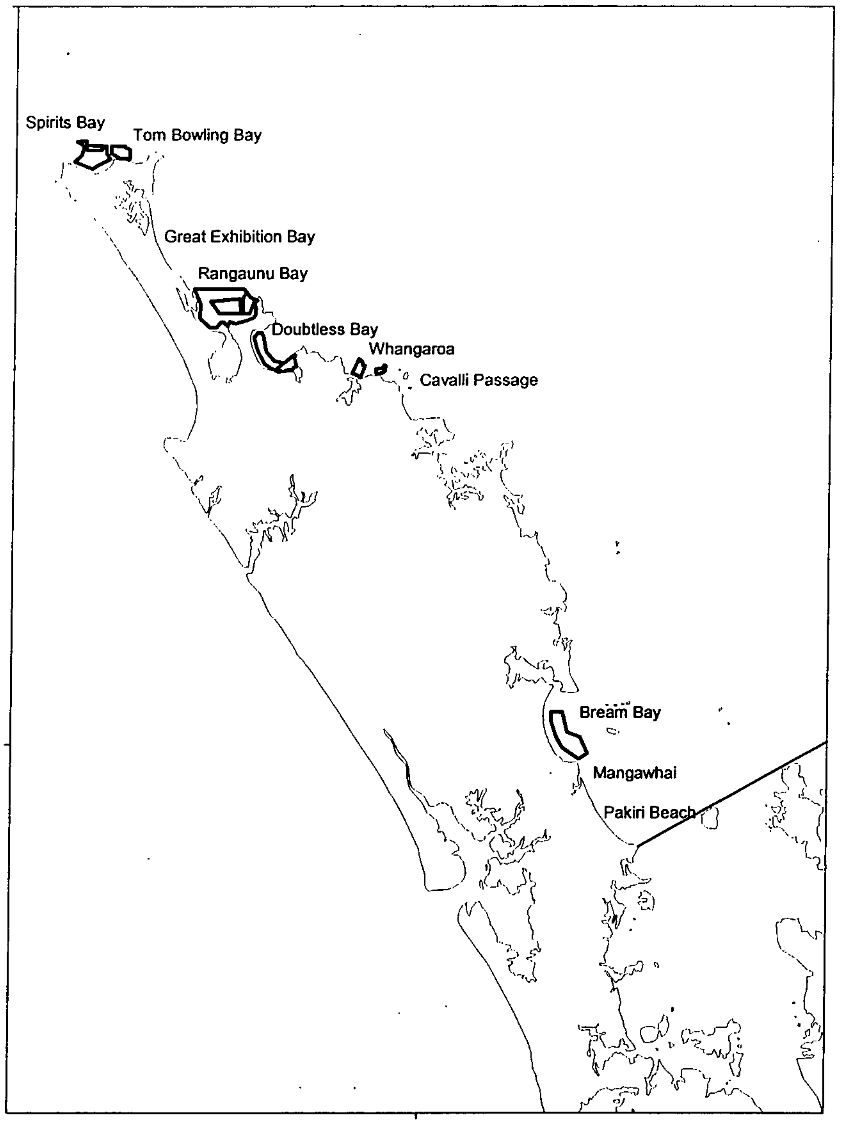

***Figure 1*: Location of strata for the survey of the Northland scallop fishery in 2001. Groups of strata are labelled with geographic descriptions used in the text (see Appendix 2 for details and stratum areas).**

Assumptions about dredge efficiency

Dredges are not 100% effective at retaining scallops and efficiency can vary widely (e.g., Allan 1984; Bull 1990; Cryer & Morrison 1997; Cryer & Parkinson 1999). All strata in 2001 surveys were sampled by dredge and therefore required correction for sampling efficiency. Separate estimates of dredge efficiency have historically been used for the two fisheries and for sandy and silty or muddy substrates separately in the Coromandel fishery (Cryer & Parkinson 1999). Relatively fewer data have been collected on silty substrates.

Unfortunately, all previous estimates of dredge efficiency and selectivity for both the Northland and Coromandel fisheries have been made using vessels other than those to do the surveys. In Northland, dredge efficiency has been estimated using vessels *Avalon*, *Wyzanne*, *Ben Gunn*, and *Marewa* whereas in the Coromandel fishery, vessels *L'Aries* and *Kataraina* have been used. No direct information on the performance of *Sheba* or *San Tam* is available. Because of this uncertainty, biomass was estimated using four different assumed rates of dredge efficiency for each fishery and substrate; these were 100% efficient, the highest previously recorded efficiency, the upper limit of a 95% confidence distribution of historical average efficiency, and the historical average efficiency (Table 1). Uncertainty about these assumed levels of efficiency was assumed to be zero at 100% efficient, and could be estimated using the *c.v.* of all historical estimates for the historical average efficiency, but could not be easily estimated for the other two approaches. A nominal *c.v.* of 20% was used in these cases. Clearly, assuming 100% dredge efficiency is the most precautionary approach because observed density estimates are effectively un-scaled for dredge efficiency which is likely to be less than 100%. However, some estimates of dredge efficiency in Northland have been close to 100%. Adopting historical average dredge efficiency is the least precautionary approach because the vessel or dredge used in 2001 may have been more efficient than those used previously.

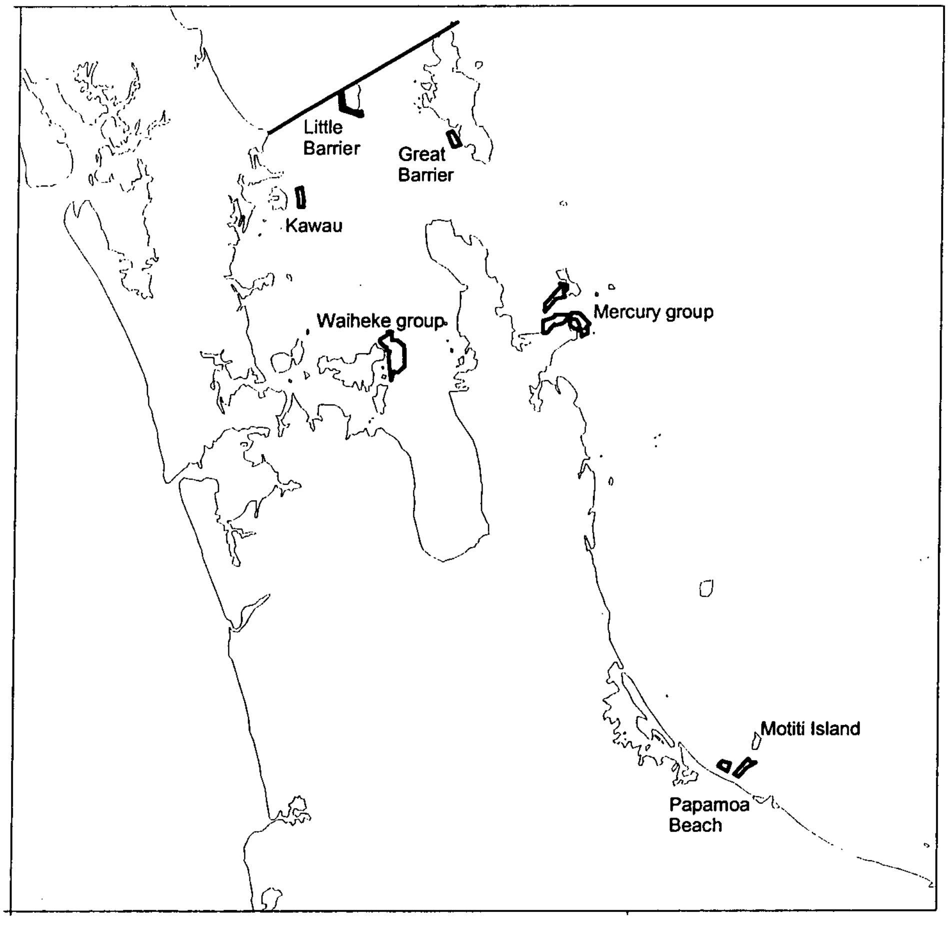

***Figure 2*: Location of strata for the survey of the Coromandel scallop fishery in 2001. Groups of strata are labelled with geographic descriptions used in the text (see Appendix 2 for details and stratum areas).**

Length frequency estimation and scaling

Where subsampling was undertaken, an estimate of the sample length frequency was made by scaling each count within the distribution by the inverse of the estimated sampling fraction. Estimated stratum length frequency distributions were derived by weighted averaging of all (estimated) length frequency samples taken within each stratum, weights being proportional to the estimated total density of scallops at each site. Stratum length frequency distributions were scaled to the estimated total abundance of scallops within each stratum using the overall fraction sampled in each stratum. Fully scaled length frequency distributions for any particular combination of strata were then derived by addition of stratum length frequency distributions. All length frequency distributions were corrected for dredge selectivity at length (in 10 mm size classes, Table 2). This approach is likely to be improved after dredge efficiency has been analysed more thoroughly.

***Table 1*: Scaling factors ("multipliers") and their *c.v.*s used to correct for dredge efficiency for scallops of a size likely to recruit to the Northland and Coromandel fisheries by the start of the season in July 2001. Four alternative approaches were used based on 100% efficiency, the highest recorded efficiency, the upper limit of a 95% confidence distribution of historical average efficiency, and the historical average efficiency for all survey vessels.**

Northland fishery	Sandy substrates			Silty substrates		
	Efficiency	Multiplier	*c.v.*	Efficiency	Multiplier	*c.v.*
No scaling	100.0	1.000	0.0%	–	–	–
Highest historical	94.9	1.054	20.0%	–	–	–
Upper 95% limit	78.4	1.276	20.0%	–	–	–
Historical average	63.7	1.570	9.7%	–	–	–

Coromandel fishery	Sandy substrates			Silty substrates		
	Efficiency	Multiplier	*c.v.*	Efficiency	Multiplier	*c.v.*
No scaling	100.0	1.000	0.0%	100.0	1.000	0.0%
Highest historical	77.0	1.300	20.0%	70.0	1.431	20.0%
Upper 95% limit	51.6	1.938	20.0%	45.3	2.207	20.0%
Historical average	41.0	2.437	10.2%	32.3	3.096	14.4%

***Table 2*: Dredge multipliers applied to 1999 and 2001 survey length frequency distributions to estimate population length frequency distributions in Northland and Coromandel fisheries. These multipliers are not necessarily those used to estimate recruited biomass**

Length class (mm)	Sandy substrates	Silty substrates
< 60	6.689	7.955
60–69	5.626	6.690
70–79	4.562	5.425
80–89	3.500	4.162
≥ 90	2.437	3.096

Biomass estimation

Estimation of the likely density of scallops over a given size at the start of season requires information on likely growth rate and mortality. Previous analyses (e.g., Cryer & Parkinson 1999) have relied on an assumption that, on average, scallops of 95 mm or greater at the average time of surveys will be 100 mm or greater at the start of season in mid-July. When the size limit was decreased from 100 to 90 mm for the commercial fishery, the critical size was concomitantly reduced to 85 mm. This approach is repeated here. Growth rate varies among years and with depth (Cryer & Parkinson 2000) and this may not be an optimal approach.

Counts of scallops over the critical size at each site were converted to numbers per square metre of seabed according to the area swept by the dredge and, where appropriate, the sampling fraction. The mean scallop density and its associated variance were calculated for each stratum using standard parametric methods, and the number of scallops calculated by multiplying the density by the area of the stratum.

The total number of scallops in the two groups of strata covered by the two sampling methods (dredge on sand and dredge on mud) were then derived by summing the stratum totals within the groups. Sampling *c.v.*s for the overall estimate of scallop numbers in each group of strata were derived using the formula for strata of unequal sizes (equation (1)) after Snedecor & Cochran (1989).

$$s^2_{(y)} = \sum A_i^2 . S^2_i . (1 - \phi_i) / n_i \qquad (1)$$

where $s^2_{(y)}$ is the variance of the estimated overall number of scallops in the surveyed area, A_i is the relative size of stratum i, and S_i^2 and n_i are the sample variance and the number of samples respectively from that stratum. The finite correction term, $(1 - \phi)$, was set to unity because the sampling fraction was less than 0.01 in all strata. The standard error (SEM) of the overall mean is simply the square root of this variance, and the *c.v.* is the ratio of the standard error to the mean. If the estimates of stratum size are assumed to be without error, then the *c.v.*s of the two population estimates (by substrate) are proportionately the same as those for the estimates of overall mean densities. These two estimates of population abundance and their variances are not corrected for sampling efficiency.

Corrections for dredge efficiency on sand (and, for the Coromandel fishery, mud) were made by multiplying the estimated abundance of scallops over the critical size by a scalar, either 1.0, the mean of the reciprocals of all historical estimates of dredge efficiency for scallops of 90 mm or greater, or two other precautionary estimates of average dredge efficiency. Dredges were assumed to be similarly efficient for all scallops larger than 85 mm shell length and the same dredge efficiency corrections were made for the two critical sizes of 95 and 85 mm. The overall abundance of scallops over the critical size, N_{total}, in the entire survey area (or any subset of strata), was estimated as the sum of the two estimates by sampling method from equation (2):

$$N_{total} = \sum N_j . E_j \qquad (2)$$

where N_j is the estimated abundance within strata sampled using method j (dredge on sand, dredge on mud), and E_j is the scalar (dredge multiplier) for method j. The variance for this estimate was estimated by simulation using equation (3):

$$\hat{N}_{total} = \sum (N_j + \varepsilon_{n,j}).(E_j + \varepsilon_{e,j}) \qquad (3)$$

where the $\varepsilon_{x,j}$ are random normal deviates each with a mean of zero and standard deviations equal to the standard errors associated with estimates of abundance and (reciprocal) efficiency by sampling method. A probability distribution for N_{total} was derived by generating 4000 replicate estimates of $\hat{N}_{total}$, the standard deviation of which is an estimate of the standard error of N_{total}, from which the *c.v.* can be calculated. This approach was used to estimate the variance structure and *c.v.* of estimates of biomass from the level of single stratum, through clusters of strata considered to represent "beds", to the total fishery.

This technique for estimating scallop abundance and its variance is identical to that used since 1997, except for the inclusion of alternative dredge multipliers. Before 1997, dredge efficiency was usually incorporated as a selectivity function of size which was assumed to be without variance. Given the variability of dredge efficiency estimates from this and past studies at a range of sites, the assumption of zero variance is clearly untenable, and estimates of confidence limits for biomass estimates by this method were optimistic.

Start-of-season recruited biomass for strata sampled using method j was estimated as the product of N_j (for scallops predicted to grow to MLS by the start of the season), an estimate of average weight at the start of the season, $\overline{W}_j$, and the expected survival of scallops between the mean survey date and the start of the coming season in mid-July (equation (4)):

$$B_{recruited} = \sum N_j.E_j.\overline{W}_j.e^{-(t.M)} \tag{4}$$

where M is an assumed instantaneous rate of natural mortality ($M = 0.50$ y^{-1}, Cryer 2001a) and t is the time lag (years) between the mid-point of the survey and the start of the season. Average weight was estimated for all strata sampled using method j from the pooled length frequency distribution for the strata involved and a length-weight regression from the Coromandel fishery (equation (5)):

$$W = 0.00042\, L^{2.662} \tag{5}$$

where W is the greenweight (g) and L the maximum shell length (mm, n = 861). The $\overline{W}_j$ for equation (5) were derived incorporating all scallops of 100 mm or greater shell length within strata sampled using method j at the time of the survey (equation (6)).

$$\overline{W}_j = \frac{\sum W_{l,j}.N_{l,j}}{\sum N_{l,j}} \tag{6}$$

where $N_{l,j}$ and $W_{l,j}$ are respectively the number and predicted weight (from equation 6) of scallops of length l sampled by method j. This estimate was assumed also to be the average weight of individuals likely to be still alive at the start of the forthcoming season (making the implicit assumption that after growth and mortality, the population length frequency distribution would remain the same).

The variance for the estimated start of season recruited biomass was estimated by simulation using equation (7):

$$\hat{B}_{recruited} = \sum (N_j + \varepsilon_{n,j}).(E_j + \varepsilon_{e,j}).\overline{W}_j.e^{-(t.M)} \tag{7}$$

where the $\varepsilon_{x,j}$ are random normal deviates each with a mean of zero and standard deviations equal to the standard errors associated with estimates of abundance and (reciprocal) efficiency by sampling method. A probability distribution for $B_{recruited}$ was derived by generating 4000 replicate estimates of

$\hat{B}_{recruited}$, the standard deviation of which is an estimate of the standard error of $B_{recruited}$, from which the *c.v.* can be calculated.

Prediction of seasonal average recovery fraction

The Total Allowable Commercial Catch (TACC) for the Northland fishery and catch limits for the Coromandel fishery are both specified in meatweight (the weight of muscle and roe combined), whereas assessments are carried out in numbers of scallops or their aggregate greenweight as these are more tractable. The average "condition" of scallops (meatweight compared with greenweight) varies with location, depth, season, and between years. Fleet average recovery rates can be as high as 20% in some weeks, but can be less than 10% just after a spawning event (usually in October or November).

Cryer & Parkinson (1999) amalgamated historical data where length, greenweight, and meatweight were available from pre-season and in-season surveys of scallops. Most of this information was collected between 1975 and 1991 during dive and dredge surveys of the Coromandel fishery, but about one third was collected during various experiments and trials conducted during the season. Cryer & Parkinson (1999) also examined the relationship between estimated greenweight and actual meatweight from CELR forms, although the necessary data are frequently not well reported by fishers. They found that, although the overall average recovery of meat from greenweight was very close to 13.5%, there was considerable variation among weeks of the year and among years. The recovery of meatweight from greenweight in a particular year will therefore vary according to whether that year is "good" or "bad" for scallop growth and condition, and when and how the stock is fished.

The prediction of average meatweight recovery for a forthcoming season is complicated by the above factors, but a value of 13.5% is assumed when converting biomass estimates from greenweight to meatweight.

Results

Pooled length frequency distributions

In the Northland survey, 4 977 of the 7 346 scallops caught in 77 tows (covering 0.13 km^2) were measured, compared with 5 188 of the 12 666 caught in 83 tows (covering 0.13 km^2) during the Coromandel survey. Approximate pooled length frequency distributions corrected for dredge efficiency and scaled to estimated population size (assuming historical average dredge efficiency for each fishery and substrate type) are shown for the major areas of each fishery in Figures 3 and 4 (Northland fishery) and Figure 5 and 6 (Coromandel fishery).

Density and biomass estimates

Estimates of mean density, population abundance, and approximate biomass at the time of the survey are given in Tables 3 (Northland, size at recruitment 100 mm), 4 and 5 (Coromandel, for sizes at recruitment of 90 and 100 mm, respectively), assuming dredge efficiency of 95% in the Northland fishery and 77% on sandy substrates or 70% on muddy substrates in the Coromandel fishery. For the Northland fishery, about 8.9 million scallops (with a *c.v.* of 27%) within the survey area were large enough to grow to the MLS of 100 mm by the start of the season in July. The relatively large average weight of 110 g leads to a biomass estimate of about 975 t greenweight. The average density across these relatively large strata was less than 0.03 m^{-2}, except in Spirits Bay, where it was about 0.05 m^{-2}. Almost all of the biomass was in Spirits Bay and the eastern parts of Rangaunu Bay.

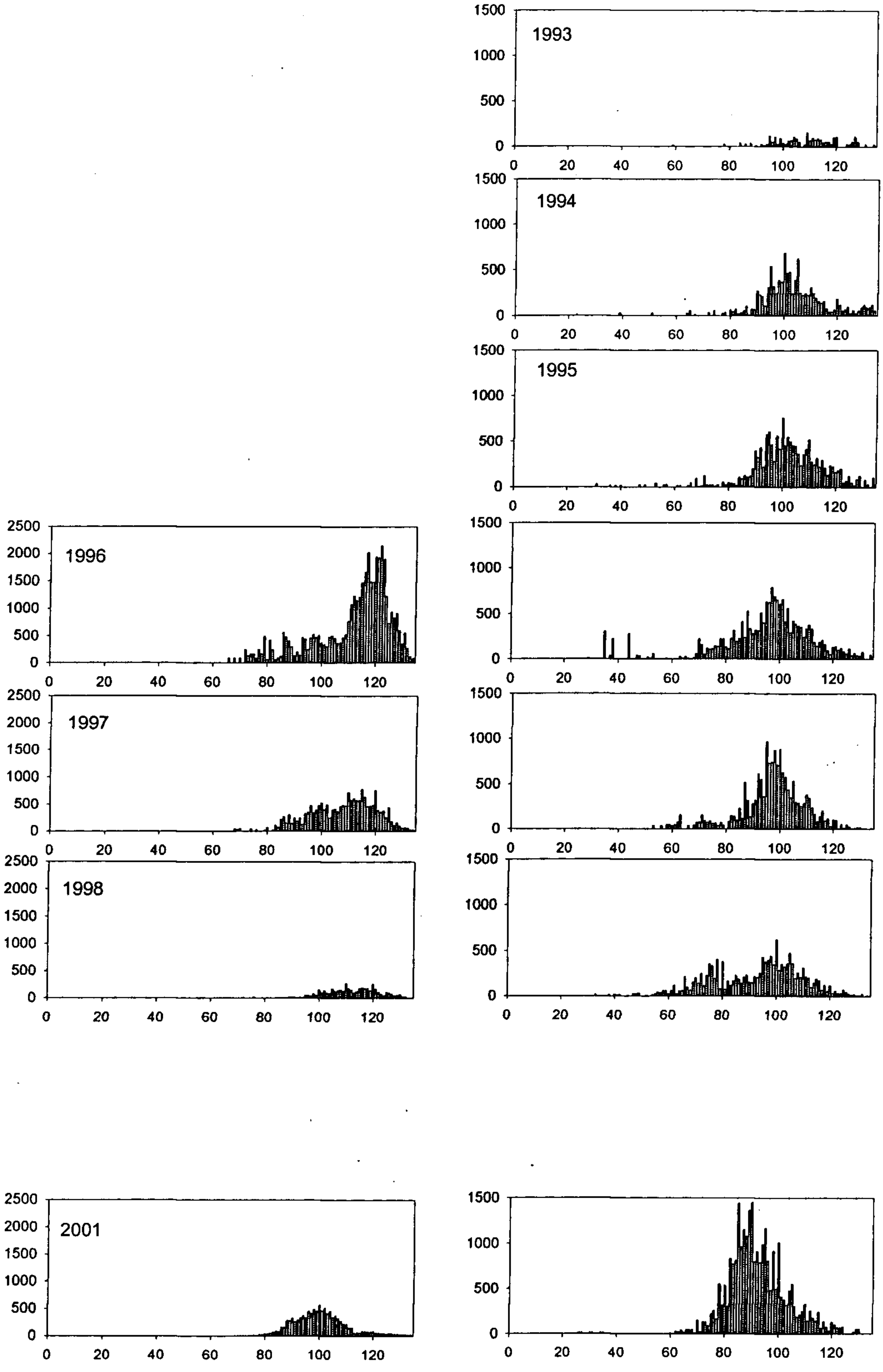

***Figure 3*: Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Spirits Bay and Tom Bowling Bay; right panel, Rangaunu Bay and Doubtless Bay. There were no surveys in Spirits Bay or Tom Bowling Bay before 1996.**

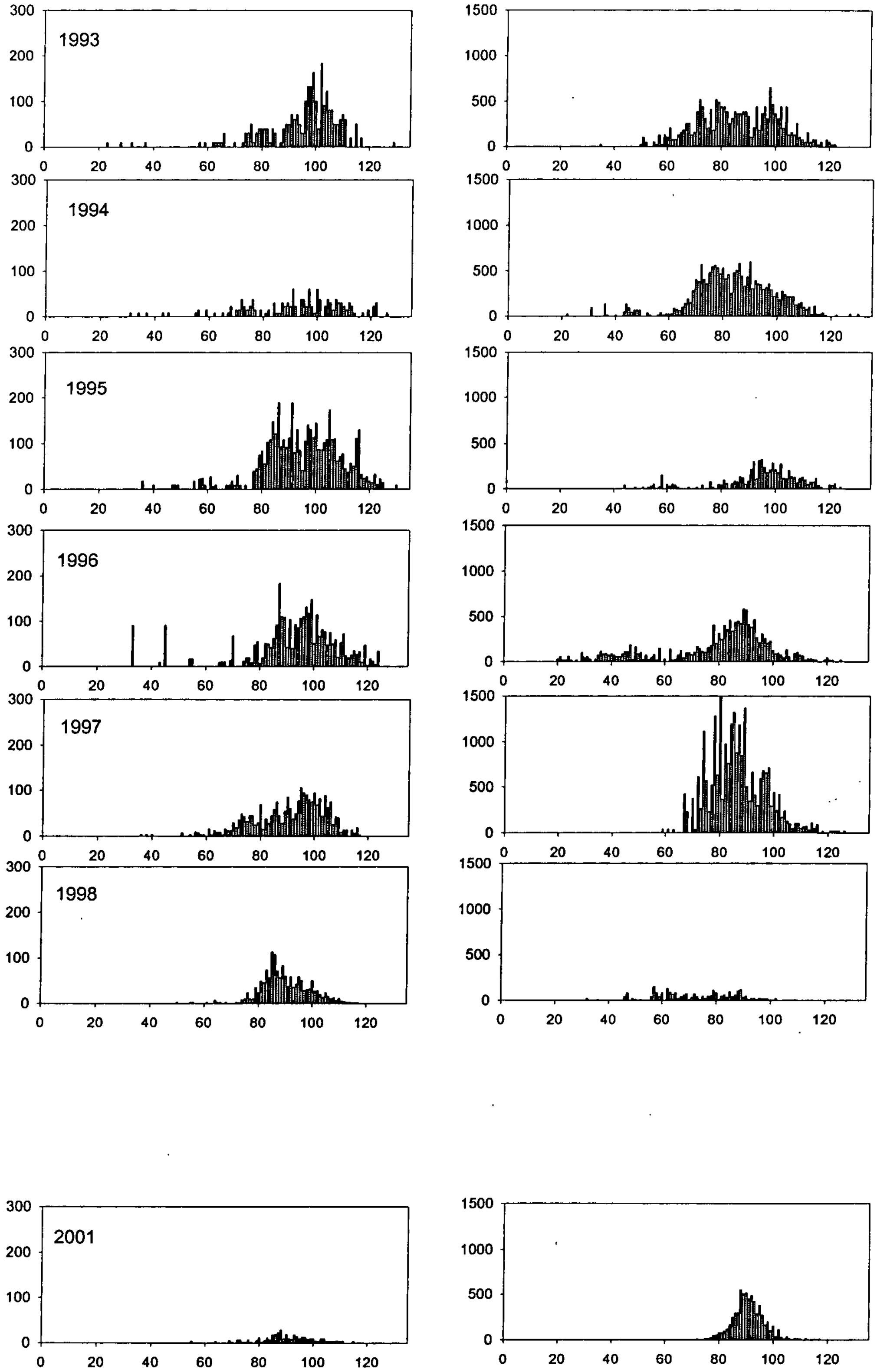

Figure 4: **Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Stevenson's Island (Whangaroa); right panel, Bream Bay. The 1997 result for Bream Bay was based on very few samples and may be unreliable.**

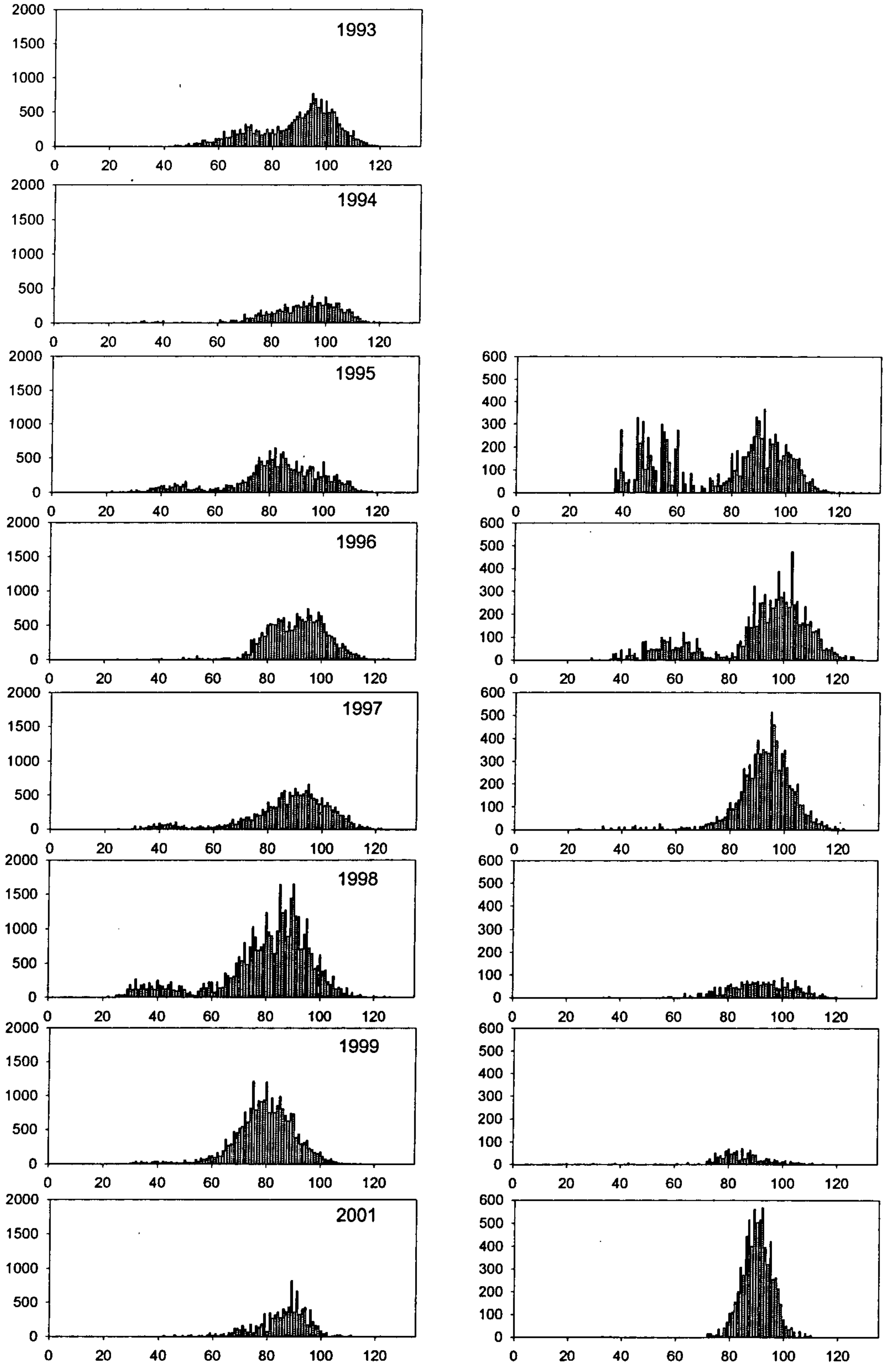

Figure 5: **Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Mercury Islands; right panel, Little Barrier Island. There were no surveys at Little Barrier Island before 1995.**

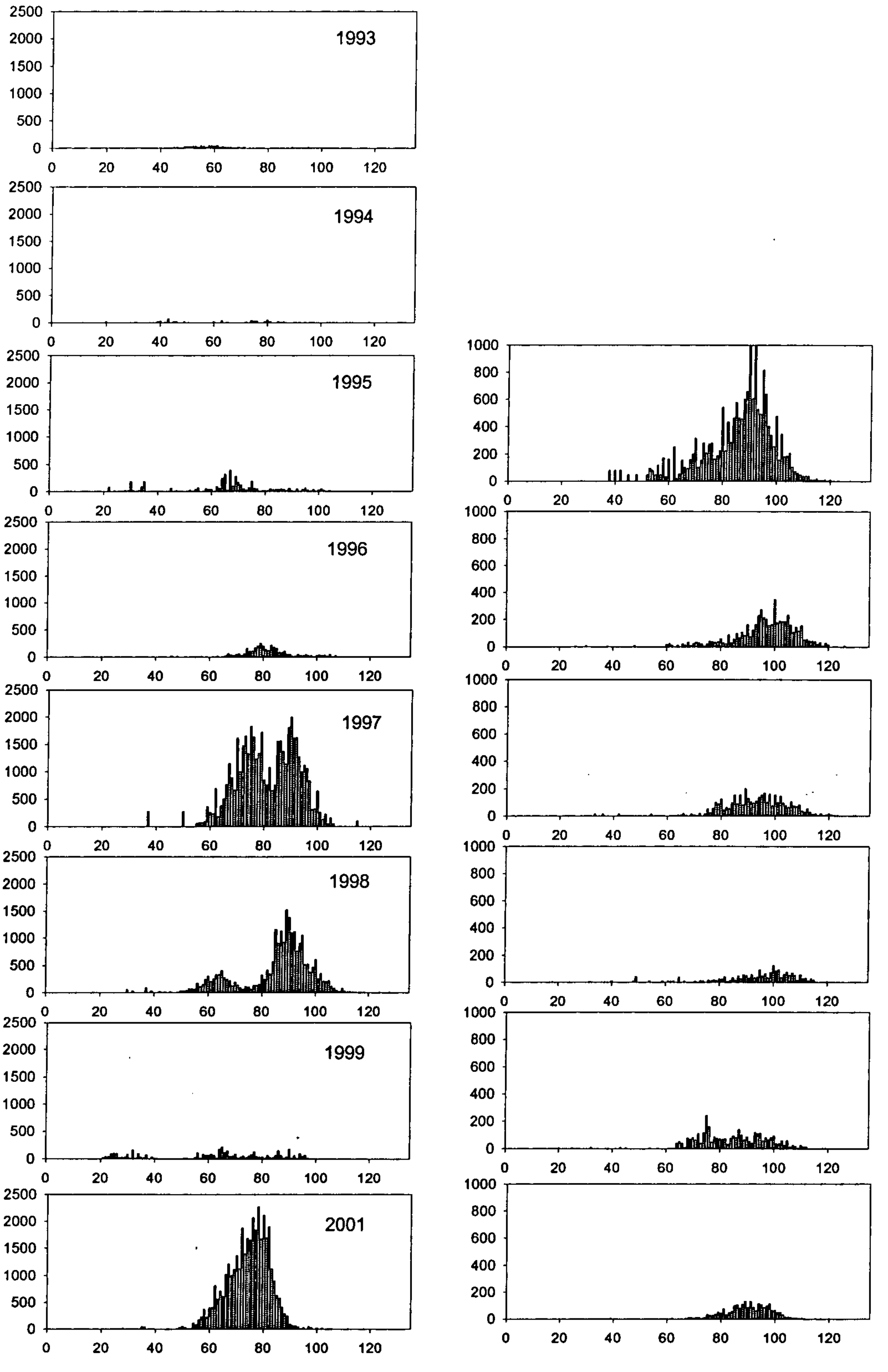

***Figure 6*: Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected using historical average dredge efficiency by size class. Left panel, Waiheke Island; right panel, Motiti and Papamoa Beach. There were no surveys at Motiti–Papamoa before 1995.**

Table 3: Summarised results (corrected using a dredge efficiency of 95% with an assumed _c.v._ of 20%) of abundance surveys for scallops in the major areas of the Northland fishery surveyed during 2001 based on a size at recruitment of 100 mm. The recruited population size is the estimated number of scallops 95 mm or greater shell length at the time of the survey, it being assumed that all such scallops will grow to 100 mm by the start of the season in July. Mean weight of recruits is estimated as the mean weight of all individuals of 100 mm shell length or greater at the time of the survey.

Bed	Population > 95 mm (millions)	Recruited density (m^{-2})	*c.v.* of recruited density	Mean weight of recruits (g)	Approx. biomass (t)
Spirits/Bowling	3.67	0.0471	0.42	111.0	407
Rangaunu	4.41	0.0240	0.29	109.1	484
Doubtless	0.00	0.0000	–	–	0
Whangaroa	0.05	0.0041	0.35	102.6	5
Bream Bay	0.75	0.0099	0.33	99.0	75
Fishery	8.89	0.0221	0.27	109.6	975

Table 4: Abundance of scallops likely to recruit (corrected using dredge efficiency of 77% on sandy substrates and 70% on silty substrates, both with an assumed _c.v._ of 20%) in major areas of the Coromandel fishery surveyed during 2001 based on a size at recruitment of 90 mm. The recruited population size is the estimated number of scallops 85 mm or greater shell length at the time of the survey, it being assumed that all such scallops will grow to 90 mm by the start of the season in July. Mean weight of recruits is estimated as the mean weight of all individuals of 90 mm shell length or greater at the time of the survey.

Bed	Population > 85 mm (millions)	Recruited density (m^{-2})	*c.v.* of recruited density	Mean Weight of recruits (g)	Approx. biomass (t)
Mercury	2.92	0.0509	0.48	76.3	223
Motiti / Papamoa	0.81	0.0658	0.32	80.9	66
G. Barrier	0.48	0.0688	0.42	76.4	37
L. Barrier	2.90	0.4535	0.40	75.8	220
Waiheke	1.15	0.0273	0.41	74.8	86
Kawau	0.00	0.0000	–	–	0
Fishery	8.26	0.0659	0.26	76.3	631

For the Coromandel fishery, about 8.3 million scallops (with a *c.v.* of 26%) within the survey area were large enough to grow to the MLS of 90 mm by the start of the season in July. The average weight of only 76.3 g leads to a biomass estimate of about 631 t greenweight. The average density across these strata was mostly more than 0.03 m^{-2}, except at Waiheke and Kawau Islands in the Hauraki Gulf, where it was less than 0.03 m^{-2}. The average density at Little Barrier Island was almost 0.5 m^{-2} and most of the biomass was there or in parts of the Mercury Island bed. Of these 8.3 million scallops, however, only about 2.2 million (27%) were large enough to grow to 100 mm by the start of the season. This estimate provides for comparison with historical estimates made when the MLS was 100 mm (1978 to 1995).

The biomass estimates are sensitive to the assumed efficiency of the dredges used in 2001, but also to exclusion of scallops in areas of low density. For instance, the estimate of recruited biomass in the Northland fishery decreases by about 6% if dredge efficiency is assumed to be 100%, increases by about 48% if historical average efficiency is assumed, and decreases by about 30% if scallops at site densities of less than 0.04 m^{-2} are excluded. The whole range of sensitivity tests for the Northland fishery was 474–1446 t. In comparison, the estimate of recruited biomass for the Coromandel fishery is more sensitive to assumptions about dredge efficiency, but less sensitive to exclusion of scallops at low density. The whole range of sensitivity tests for the Coromandel fishery was similarly broad at 403–1211 t, however.

***Table 5*: Abundance of scallops likely to reach 100 mm shell length recruit (corrected using dredge efficiency of 77% on sandy substrates and 70% on silty substrates, both with and assumed *c.v.* of 20%) in major areas of the Coromandel fishery surveyed during 2001. The recruited population size is the estimated number of scallops 95 mm or greater shell length at the time of the survey, it being assumed that all such scallops will grow to 100 mm by the start of the season in July. Mean weight of recruits is estimated as the mean weight of all individuals of 100 mm shell length or greater at the time of the survey.**

Bed	Population > 95 mm (millions)	Recruited density (m^{-2})	*c.v.* of recruited density	Mean Weight of recruits (g)	Approx. biomass (t)
Whitianga	0.77	0.0135	0.45	98.0	76
Motiti	0.38	0.0311	0.34	96.4	37
G. Barrier	0.11	0.0165	0.49	92.5	11
L. Barrier	0.85	0.1328	0.43	95.2	81
Waiheke	0.09	0.0022	0.95	91.0	9
Kawau	0.00	0.0000	–	–	0
Fishery	2.22	0.0177	0.29	96.2	213

***Table 6*: Sensitivity of estimates of recruited biomass (B: top, Northland fishery, scallops ≥ 95 mm; bottom, Coromandel fishery, scallops ≥ 85 mm) at the time of surveying to different assumptions about dredge efficiency and the critical density of scallops. The assumptions made in presenting the distribution of recruited biomass in Tables 3 and 4 are shown in bold.**

Northland fishery							Critical density (m^{-2})	
	0.00		0.02		0.04		0.06	
	B (t)	*c.v.*	B (t)	*c.v.*	B (t)	*c.v.*	B (t)	*c.v.*
No scaling	921	0.18	795	0.22	630	0.25	474	0.36
Highest historical	**975**	**0.27**	850	0.30	683	0.32	532	0.38
Upper 95% limit	1 180	0.27	1 045	0.29	866	0.30	731	0.35
Historical average	1 446	0.21	1 296	0.24	1 215	0.25	1 019	0.26

Coromandel fishery							Critical density (m^{-2})	
	0.00		0.02		0.04		0.06	
	B (t)	*c.v.*	B (t)	*c.v.*	B (t)	*c.v.*	B (t)	*c.v.*
No scaling	479	0.20	440	0.23	413	0.24	403	0.25
Highest historical	**631**	**0.26**	608	0.27	563	0.30	541	0.30
Upper 95% limit	946	0.27	925	0.27	863	0.30	843	0.30
Historical average	1 211	0.22	1 195	0.23	1 171	0.23	1 096	0.24

Growth rates

Very few tag recoveries have been recorded from the Northland or Coromandel fishery since 1999, and the estimates of fishery-wide growth rate summarised by Cryer (2001a) for the Coromandel fishery have not been revised. Those estimates suggest annual growth of 7–15 mm for animals of 95 mm shell length with faster growth between May and October than at other times. The faster growth rates were measured in shallow water (about 10 m). Scallops of 85 mm are predicted by this model to grow 10–23 mm each year. If growth is assumed steady throughout the year, a scallop of 85 mm shell length at the time of the survey in mid-May is predicted to grow to 87–89 mm by the start of the season in mid-July and to 91–99 mm by the end of the season in December. Seasonally variable growth would increase the former, perhaps the latter. Scallops in the Northland fishery may grow slightly faster but the relatively few data available suggest average annual growth of 9–12 mm, with faster growth between June and October. Growth in the Northland fishery seems less dependent on depth (Cryer & Parkinson 1999). The survey in the Northland fishery was conducted earlier, almost 3 months before the start of the season. If growth is assumed steady throughout the year, a scallop of 95 mm shell length at the time of the survey in mid-late-April is predicted to grow 97–98 mm by the start of the season in mid-July and to 102–105 mm by the end of the season in February. Seasonally variable growth would increase the former.

Start-of-season recruited biomass in the Northland fishery (at 100 mm)

To predict start-of-season recruited biomass in the Northland fishery, assumptions about growth and mortality between the time of survey and the start of the season must be made. The mid-point of the survey was 24 April, 82 days before the start of the 2001 season (nominally 15 July). It is assumed that most scallops of 95 mm or more in shell length would grow to 100 mm by the opening of the season or shortly afterward, but this may be sensitive to the depth distribution of scallops close to the minimum legal size (Cryer 2001a) and to the (unpredictable) growth conditions in 2001. Assuming a natural mortality rate of M = 0.50 spread evenly over the year (Cryer 2001a) leads to mortality of about 10.6% between survey and season.

Recruited biomass, from equation (4), is essentially the product of the abundance of scallops of 95 mm or more shell length at the time of the survey (assuming dredge efficiency of 95%), their expected average weight at the start of the season, and their expected survival rate of 89.4%. For the surveyed beds in 2001, this equates to

8.894 million * 109.59 * 0.894 = 871 t (greenweight), or

assuming 13.5% recovery, 871 * 0.135 = 118 t (meatweight)

These estimates both have a *c.v.* of 27% which includes variance associated with the assumed average dredge efficiency, but not associated with estimates of growth rate, mortality rate, mean weight, or expected recovery fraction. They are also sensitive to assumptions about dredge efficiency in 2001 and exclusion of sites at which the density of recruited scallops was low.

Start-of-season recruited biomass in the Coromandel fishery (at 90 mm)

To predict start-of-season recruited biomass in the Coromandel fishery, assumptions about growth and mortality between the time of survey and the start of the season must be made. The mid-point of the survey was 10 May, 65 days before the start of the 2001 season (nominally 15 July). It is assumed that most scallops of 85 mm or more in shell length would grow to 90 mm by the opening of the season or shortly afterward, but this may be sensitive to the depth distribution of scallops close to the minimum legal size (Cryer 2001a) and to the (unpredictable) growth conditions in 2001. Assuming a natural mortality rate of M = 0.50 spread evenly over the year leads to mortality of about 8.6% between survey and season.

Recruited biomass, from equation (4), is essentially the product of the abundance of scallops of 85 mm or more shell length at the time of the survey (assuming dredge efficiency of 77 or 70%), their expected average weight at the start of the season, and their expected survival rate of 91.4%. For the surveyed beds in 2001, this equates to

8.265 million * 76.36 * 0.914 = 577 t (greenweight), or

assuming 13.5% recovery, 577 * 0.135 = 78 t (meatweight)

These estimates both have a *c.v.* of 27% which includes variance associated with estimates of average dredge efficiency, but not associated with estimates of growth rate, mortality rate, mean weight, or expected recovery fraction. They are also sensitive to assumptions about dredge efficiency in 2001 and exclusion of sites at which the density of recruited scallops was low.

Start-of-season recruited biomass in the Coromandel fishery (at 100 mm)

For comparison with survey results between 1978 and 1995, and for estimation of Provisional Yield (PY, Cryer 1994), it is here assumed that all scallops of 95 mm or greater length will grow to 100 mm between the survey and the start of the season.

Recruited biomass at 100 mm, using equation (4), is essentially the product of the abundance of scallops longer than 95 mm in shell length at the time of the survey, their expected average weight at the start of the season, and their expected survival rate of 91.45%. For the surveyed beds in the Coromandel fishery in 2001, this equates to

2.217 million * 96.21 * 0.914 = 195 t (greenweight), or

assuming 13.5% recovery, 195 * 0.135 = 26 t (meatweight)

These estimates both have a *c.v.* of 29% which includes variance associated with estimates of average dredge efficiency, but not associated with estimates of growth rate, mortality rate, mean weight, or expected recovery fraction. They are also sensitive to assumptions about dredge efficiency in 2001 and exclusion of sites at which the density of recruited scallops was low.

Discussion

Discerning trends in the biomass of recruited scallops in either fishery is complicated by changes to survey coverage, the establishment of closed areas, and uncertainty about dredge efficiency in any particular year. However, some of the changes have been so large as to transcend this combined uncertainty. For the Northland fishery, only the bed in Rangaunu Bay has been consistent among years, all survey results apart from 1993 being between 6 and 10 million scallops large enough to grow to legal size by the start of the season. The 1993 estimate was undoubtedly biased low by a decision to survey only to about 30 m in that year. In 2001, there were large numbers of scallops just below the critical size of 95 mm; depending on the growth and survival of these scallops, this may lead to better than expected fishing late in the 2001–02 season or a greater biomass in 2002. The once prolific beds in Spirits Bay and Bream Bay have both declined but, in both areas, the 2001 survey result were slightly better than the last survey in 1998 (there is little evidence from the performance of the fishery that biomass was much different in the intervening years). Both Doubtless Bay and Stevenson's Island (Whangaroa) held very few scallops in 2001, however. Great Exhibition Bay, the various beds of the Cavalli Passage, and the coast at Mangawhai and Pakiri were not surveyed in 2001 because they were not expected to hold many scallops.

***Table 7*: Number of scallops at the time of survey in constituent areas of the Northland fishery since 1992 (millions 95 mm or greater shell length assuming historical average dredge efficiency of 64% for all years). Total includes data from beds not mentioned specifically. Asterisks (*) indicate unreliable results, dashes (–) indicate no survey**

	Spirits	Rangaunu	Doubtless	Whangaroa	Cavalli	Bream	Pakiri	Total
1992	–	7.0	0.7	–	0.4	16.8	4.0	28.9
1993	–	*1.5	0.7	1.7	0.4	5.5	–	9.8
1994	–	8.5	1.3	0.6	–	4.2	0.2	14.8
1995	–	9.0	1.0	2.3	1.2	3.5	0.1	18.2
1996	24.4	7.7	0.3	1.2	0.9	2.2	–	37.6
1997	15.8	9.9	0.7	1.1	0.7	*5.7	0.4	35.3
1998	4.7	6.0	0.3	0.5	0.9	0.2	<0.1	14.0
1999	–	–	–	–	–	–	–	–
2000	–	–	–	–	–	–	–	–
2001	5.4	6.6	0.0	0.1	–	1.1	–	13.2

The Mercury Island scallop beds close to Whitianga have been surveyed by divers almost annually since 1980, but most other beds have been surveyed only in recent years (Table 7). Other than that at Little Barrier Island, all beds appear to be in poor condition, even by the standard of recent years which were poor by historical standards. The mainstay of the fishery at Whitianga has the lowest recorded abundance of scallops since surveying began in 1978, though perhaps not much worse than in 1999 (the area surveyed in 2001 was considerably smaller than that surveyed in 1999). *Chaetopterus* tubeworms were abundant and a hindrance to surveying (filling the dredge and causing it to "fly") throughout the Whitianga beds, except for Opito Bay. The bed at Little Barrier Island appears much improved, and *Chaetopterus* tubeworms were a hindrance in only about half of the shots conducted. Although scallops were very numerous at Waiheke Island, they were mostly very small and few are likely to recruit to the fishery in 2001. *Chaetopterus* tubeworms were uncommon but widespread. A much smaller area was surveyed at Motiti–Papamoa in 2001 than previously, but the 2001 result suggests a biomass not much changed since 1999. Previously unsurveyed beds in deep water (about 40 m) off Kawau and Great Barrier Islands did not hold large numbers or densities of scallops in 2001. *Chaetopterus* tubeworms were uncommon at both. Beds at Waihi, Shoe, Slipper, and Colville were not surveyed because they were not expected to contain many scallops. Overall, the survey gives a slightly higher estimate of total biomass of scallops (100 mm or greater length) than in 1999, but from a significantly smaller area. This is largely because of the improvement at Little Barrier Island.

Table 8: **Number of scallops at the time of survey in constituent areas of the Coromandel fishery since 1990 (millions 95 mm or greater shell length assuming historical average dredge efficiency for all years, including 2001 when a different vessel was used). Total includes data from previously unsurveyed beds at Great Barrier and Kawau Islands. Dashes (–) indicate no survey**

	Whitianga	Waihi	Motiti, Papamoa	Little Barrier	Colville	Waiheke	Total
1990	7.4	–	–	–	–	6.4	13.8
1991	11.1	–	–	–	–	2.8	13.9
1992	10.7	–	–	–	–	0.7	11.4
1993	6.6	7.1	–	–	0.3	0.4	14.4
1994	4.8	1.5	–	–	–	0.0	6.3
1995	4.4	0.6	4.5	2.5	0.1	0.3	12.5
1996	6.1	0.2	2.2	3.3	0.1	0.3	12.6
1997	6.1	0.7	1.9	4.0	0.3	5.4	18.4
1998	6.4	0.1	1.2	1.0	0.2	5.3	14.2
1999	1.8	0.2	0.9	0.2	0.0	0.2	3.3
2000	–	–	–	–	–	–	–
2001	1.5	–	0.7	1.6	–	0.2	4.2

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Appendix 1: **Stratum definitions and station allocations, Northland scallop survey 2001**

Stratum	Location / description	Area (m^2)	Method	2001 Shots
91	Spirits Bay	49 050 781	Dredge (sand)	10
93	Spirits Bay, main bed	7 754 883	Dredge (sand)	3
92	Tom Bowling Bay	20 843 750	Dredge (sand)	4
4	Rangaunu high density E	16 688 721	Dredge (sand)	7
8	Rangaunu high density W	35 003 906	Dredge (sand)	8
13	Rangaunu medium density	132 978 271	Dredge (sand)	3
14	Doubtless Bay N	36 527 832	Dredge (sand)	3
18	Doubtless Bay S	16 682 617	Dredge (sand)	4
19	Stevenson's Island	12 347 656	Dredge (sand)	12
20	Bream Bay	75 334 961	Dredge (sand)	
Total	–	403 213 378	–	

Appendix 2: **Stratum definitions and station allocations, Coromandel scallop survey 2001**

Stratum	Location / description	Area (m^2)	Method	2001 Shots
1	Mercury (Sarah's Gully)	17 062 195	Dredge (sand)	7
3	Mercury Opito Bay	5 393 677	Dredge (sand)	3
3.5	Mercury Opito Bay deeps	13 923 828	Dredge (sand)	5
4	Mercury Cove	1 713 959	Dredge (mud)	4
8	Mercury Deeps	12 218 994	Dredge (sand)	6
13	Motiti South	4 572 998	Dredge (sand)	13
14	Papamoa	7 808 594	Dredge (sand)	7
18	Barrier West	2 934 448	Dredge (sand)	6
19	Barrier South	3 460 083	Dredge (sand)	6
20	Waiheke Island	42 260 620	Dredge (mud)	18
41	Kawau / Flat Rock	7 071 045	Dredge (mud)	4
42	Great Barrier Island	6 947 754	Dredge (sand)	4
Total	–	125 368 195	–	83

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