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Biomass survey and stock assessment for the Coromandel scallop fishery, 2008

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EXECUTIVE SUMMARY

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A dredge survey for scallops was carried out in the Coromandel scallop fishery in May 2008, with a total of 119 valid stations (dredge tows) sampled. Absolute start-of-season biomass over 90 mm shell length (the commercial minimum legal size in the Coromandel fishery) was predicted to be 6900 t greenweight or 868 t meatweight (median projected values) with c.v.s of 28 and 31%, respectively. These estimates are sensitive to assumptions about dredge efficiency, growth and mortality between survey and season, expected recovery of meatweight from greenweight, exclusion of areas of low scallop density, and relate to the surveyed beds only. These results suggest a continuation of the decline in the Coromandel fishery recruited biomass since about 2005–06, with the biomass in 2008 being at about the level of the long term average (1980 to present). However, most (about 86%) of this biomass was held in the Mercury Islands beds, which collectively form the mainstay of the fishery. Biomass in this area was still high in 2008 (about 35% above the long-term average) compared with historical records.

Yield estimates (as CAY) were produced for two scenarios, by applying two different estimates of a reference rate of fishing mortality ($F_{0.1}$) to the 2008 estimates of start-of-season recruited biomass. Incorporating only the direct incidental effects of fishing (on growth and mortality of adult scallops) and assuming average values for important assumed variables, CAY for the 2008 start-of-season was estimated to be 276 t meatweight. Incorporating both the direct and indirect incidental effects of fishing (putative habitat effects on juvenile mortality) reduced the CAY estimate to about 189 t meatweight. For both scenarios, the estimates of CAY would have c.v.s at least as large as those of the estimates of start-of-season recruited biomass (28–31%), are sensitive to assumptions about dredge efficiency, growth and mortality, expected recovery of meatweight from greenweight, and relate to the surveyed beds only. There is also additional uncertainty associated with using single point estimates of $F_{0.1}$ (i.e., variance associated with each point estimate was not incorporated in the analysis). Further, the second approach which includes putative habitat effects was also sensitive to the duration of any habitat-mediated increase in juvenile mortality.

Substantial uncertainty remains in this stock assessment, and future research and management should be aimed at reducing this uncertainty.

1. INTRODUCTION

1.1 Overview

This report summarises research and fishery information for scallops (*Pecten novaezelandiae*) in the Coromandel fishery (SCA CS). The results of a Coromandel scallop biomass survey undertaken in May 2008 are summarised and yield estimates for 2008 are derived using methods detailed by the Ministry of Fisheries Science Group (2006). Unlike in recent years (e.g., 2007, see Williams 2008), MFish did not require a biomass survey and stock assessment of Northland scallops (SCA 1) in 2008.

This work was carried out under the Ministry of Fisheries project SCA2007/01A: Stock assessment of Coromandel scallops. The overall objective was to carry out a stock assessment of scallops in the Coromandel fishery, including estimating abundance and sustainable yields. Specific objectives were:

1) to carry out a survey in about May/June 2008 to estimate the absolute abundance and population size frequency of scallops in the main scallop beds. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance was 20%.

2) to estimate the yield following the completion of the survey described in Objective 1.

1.2 Description of the northern scallop fisheries

Scallops support regionally important commercial fisheries and an intense non-commercial interest off the northeast coast of the North Island. Both the Coromandel (SCA CS) and Northland (SCA 1) commercial fisheries are managed under the Quota Management System (QMS); the two are divided by a line from Cape Rodney to the northernmost tip of Great Barrier Island (Figure 1). A wide variety of effort controls and daily catch limits has been imposed in the past, but both fisheries have been limited by explicit seasonal catch limits specified in meatweight (processed weight, being the adductor muscle plus attached roe) since the early to late 1990s. Some additional controls remain 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 (Tables 1 and 2), a characteristic of scallop fisheries worldwide (Shumway & Sandifer 1991).

All commercial fishing is by dredge, and self-tipping “box” dredges are preferred to the ring bag designs in common use in southern fisheries. In the Coromandel fishery, the main commercially fished beds are found north of Whitianga (to the west and south of the Mercury Islands group), east of Waiheke Island, to the west and south of Little Barrier Island, to the west of Great Barrier Island, and in the Bay of Plenty (principally off Waihi, and around Motiti and Slipper Islands). Fishing in the Northland fishery is within discrete beds in Spirits Bay, Tom Bowling Bay, Great Exhibition Bay, Rangaunu Bay, Doubtless Bay, Stephenson Island, the Cavalli Passage, Bream Bay, the coast between Mangawhai and Pakiri Beach, and to the north of Little Barrier Island. 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 both fisheries was 100 mm (shell length) 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. The MLS has remained at 100 mm for the Northland fishery and for all non-commercial fishers.

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 PhD theses by Morrison (1997) and Williams (2005), and some papers on reproductive ecology (Williams & Babcock 2004, Williams & Babcock 2005). 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 and in the Northland fishery in depths of 20 to 50 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.

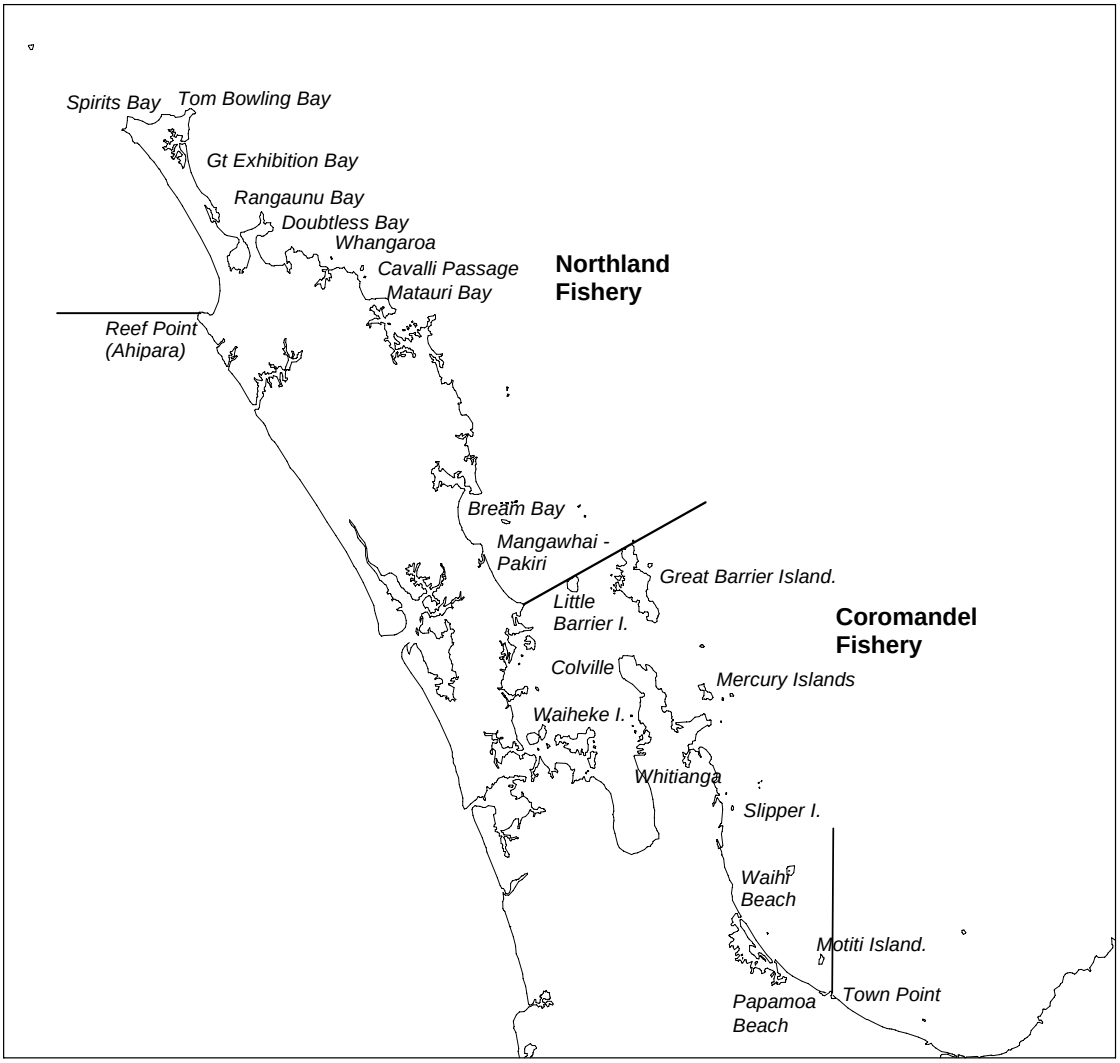

Figure 1: Geographic distribution of the two northern scallop fisheries and the names of locations mentioned in the text. After Cryer & Parkinson (2006).

Pecten novaezelandiae is hermaphroditic; each individual carries both male and female gonads at the same time. Most individuals are sexually mature at about 60–70 mm shell length (see Williams (2005) and Williams & Babcock (2005) for a comprehensive treatment in the Hauraki Gulf), although larger individuals have disproportionately larger gonads. They are extremely fecund and can spawn several times each year (Williams & Babcock 2004), although not all spawning events lead to successful spat settlement. Larval development lasts for about three 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.

Simulation modelling by Cryer et al. (2003) suggested that strategies that vary catch in proportion to biomass (constant-*F* strategies) should outperform constant catch strategies. This is not surprising, but constant-*F* strategies provide about 30% more catch at higher catch rates with lower biological risk. "Tuning" the exploitation rate (especially to conservative levels) and setting it to zero at low biomass both decreased biological risk. Conversely, maintaining a "base" TACC (the current management strategy) increased biological risk. Full cost-benefit analysis was not undertaken but, over the long run, the additional model catch available from a constant-*F* strategy had a much higher value than the cost of the necessary surveys, and there were additional benefits in terms of higher average catch rates and lower biological risk. Rotational fishing provided good levels of catch at relatively low biological risk, but needed high rates of exploitation in the open areas. These high rates of extraction might not be economically sensible (because of low catch rates as biomass declines during a year), or environmentally sustainable (because of reduced habitat structure).

2. REVIEW OF THE COROMANDEL FISHERY

2.1 TACCs, catch, landings, and effort data

Coromandel scallops (SCA CS) were introduced into the Quota Management System (QMS) on 1 April 2002 with a Total Allowable Catch (TAC) of 48 t meatweight, comprised of a Total Allowable Commercial Catch (TACC) of 22 t, recreational and customary allowances of 7.5 t each, and an allowance of 11 t for other sources of mortality. The fishery has 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 level of the TACC at the end of each season (15 July to 21 December). The fishery is managed using individual transferable quotas (ITQ) that are proportions of the TACC. Catch rates are variable both within and among seasons, but the relationship between biomass and catch per unit effort (CPUE) is complex and (declines in) CPUE cannot be used to estimate biomass within a season (Cryer 2001). Effort data, therefore, are not presented.

Since 1980 when the fishery was considered to be fully developed, commercial landings have varied more than 30-fold from less than 50 t to over 1500 t greenweight (Table 1). Since 2002 when SCA CS entered the QMS, landings have been close or equal to the catch limit set, except for in 2007 when landings were only 55% of the agreed catch limit. Commercial fishers reported three main reasons for landing less than the expected catch in 2007: 1) frequent easterly storms reduced the number of fishing days, 2) scallop meatweight condition was generally poor, possibly as a result of spawning induced by the storms, and 3) fishers jointly agreed to end the season early (in November rather than December) because of concerns about the unusually large number of pre-recruit scallops they were catching. Stopping fishing would protect these scallops from potential damage by dredging, with the view that they could survive and grow into the recruited biomass for the 2008 season.

Table 1: Catch limits and landings (t meatweight or greenweight) from the Coromandel scallop fishery (SCA CS) 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. Landings figures come from Monthly Harvest Return (MHR) forms, Licensed Fish Receiver Return (LFRR) forms, and from the landed section of Catch Effort and Landing Return (CELR) forms. Estimated catch figures come from the effort section of CELRs and are pro-rated to sum to the total CELR greenweight. "Barrier" = 2R, 2S, and 2Q, "Hauraki" = 2X and 2W, "Mercury" = 2L and 2K, "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.

			Landings (t)							
	Catch limits (t)		MHR	LFRR	CELR		Estimated catch (t green)			
Season	Meat	"Green"	Meat	Meat	Meat	Green	Barrier	Hauraki	Mercury	Plenty
1974	–	–	–	–	–	26	0	0	26	0
1975	–	–	–	–	–	76	0	0	76	0
1976	–	–	–	–	–	112	0	0	98	14
1977	–	–	–	–	–	710	0	0	574	136
1978	–	–	–	–	–	961	3	164	729	65
1979	–	–	–	–	–	790	51	282	362	91
1980	–	–	–	–	–	1 005	23	249	690	77
1981	–	–	–	–	–	1 170	41	332	743	72
1982	–	–	–	–	–	1 050	49	687	385	80
1983	–	–	–	–	–	1 553	120	687	715	31
1984	–	–	–	–	–	1 123	62	524	525	12
1985	–	–	–	–	–	877	82	518	277	0
1986	–	–	–	162	–	1 035	305	135	576	19
1987	–	–	–	384	–	1 431	136	676	556	62
1988	–	–	–	182	–	1 167	234	19	911	3
1989	–	–	–	104	–	360	95	24	253	1
1990	–	–	–	153	–	903	114	98	691	0
1991	–	–	–	203	–	1 392	98	*472	822	0
1992	154	1 232	–	147	–	901	68	67	686	76
1993	132	1 056	–	62	–	455	60	11	229	149
1994	66	528	–	49	–	323	48	17	139	119
1995	86	686	–	88	79	574	176	25	323	50
1996	88	704	–	81	80	594	193	25	359	18
1997	105	840	–	94	89	679	165	26	473	15
1998	110	880	–	37	19	204	2	1	199	1
1999	31	248	–	8	7	47	17	0	12	18
2000	15	123	–	7	10	70	2	0	24	44
2001	22	176	–	22	20	161	85	1	63	12
2002	35	280	28	32	31	204	12	0	79	112
2003	58	464	58	58	56	451	13	63	153	223
2004	78	624	78	78	78	624	27	27	333	237
2005	118	944	119	119	121	968	75	21	872	0
2006	118	944	118	118	117	934	60	28	846	0
2007	108	864	59	?	59	471	45	51	373	2

2.2 Other information

Incidental mortality caused by commercial scallop dredges was estimated in 1996–97 (Cryer & Morrison 1997). Individual-based modelling and stochastic yield-per-recruit (YPR) analysis suggest that neither the 100 mm MLS previously in force in Coromandel (and still currently in force in Northland) nor the Provisional Yield (PY) method of estimating yield were optimal (for maximising long-term average landings).

2.3 Recreational and Maori customary fisheries

There is an intense non-commercial (recreational and Maori) interest in scallops throughout the Coromandel fishery. Non-commercial fishing for scallops occurs in suitable areas throughout the fishery, 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 non-commercial 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. Regulations restrict the non-commercial daily harvest (bag limit) to 20, and there is 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. There is no overall catch limit for the non-commercial sector.

Currently, there are no reliable estimates of non-commercial harvest of scallops from the Coromandel fishery. Estimates of catch by recreational fishers have been made on four occasions as part of recreational fishing (telephone and diary) surveys (Table 2). The Marine Recreational Fisheries Technical Working Group 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 scallop harvest. However, in 1993–94 the recreational harvest from the Coromandel scallop fishery was an estimated 60–70 t greenweight (Bradford 1997). These estimates may include some Maori customary catch. Commercial landings 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 were typical of the recreational catch, but the commercial catch was very low and 1993–94 may not have been a typical year.

It is likely that the current non-commercial catch is higher than in the 1990s because of an increased human population. The shift in the non-commercial open season (since 2007) has enabled fishers to take scallops later in the summer (mid to late February and March); the typically settled weather and warm sea temperatures at this time of year might encourage more people to harvest scallops.

Table 2: Harvest estimates (number and greenweight) of scallops taken by recreational fishers in the Coromandel scallop fishery (SCA CS) 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	Number of scallops	c.v.	Weight (t green)	Reference
1993–94	626 000	0.14	60.0–70.0	Bradford (1997)
1996	614 000	0.12	62.0	Bradford (1998)
1999–2000	257 000	1.01	30.1	Boyd & Reilly (2002)
2000–01	472 000	0.47	55.3	Boyd et al. (2004)

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 analyses strongly suggest that incidental effects, especially on mortality rates, greatly affect yield from scallop dredge fisheries (Cryer & Morrison 1997). 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 (for maximising long term average landings) for the Coromandel fishery (Cryer & Morrison 1997).

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

3.2.1 Survey design and field methods

The choice of an appropriate time for surveys entails balancing the conflicting pressures of operational ease and uncertainty in the results. Early surveys (March-April) 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 (June-July) 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 effect 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.

The Coromandel survey was conducted between 9 and 18 May 2008. All sampling was undertaken by dredge and no diving to estimate dredge efficiency was done. We used the same vessel and skipper as used in most recent surveys. Single phase stratified random sampling was undertaken in 13 strata: Little Barrier Island (2 strata), Colville (1 stratum), the west and south of the Mercury Islands (7 strata), and the western Bay of Plenty (3 strata at Motiti Island, Papamoa Beach, and off the Katikati Entrance) (Figure 2; Appendix 1). In comparison with the 2007 survey, three strata were not surveyed: "Hooks" and "Waiheke" (Waiheke Island strata), and "Colville North" (Colville stratum). Furthermore, four strata at the Mercury Islands location were modified slightly: "Mercury Cove" was extended to include the shallower area to the southeast bounded by the 9 m depth contour; the northeast and northwest corners of "Three Mile Bank" were excluded; "Kennedy" was reduced by removing the deeper northern area of the stratum, and "Opito Bay" was reduced to exclude the deeper northern portion of that stratum. After excluding strata thought unlikely to be productive in 2008 and areas closed to commercial fishing, the total sampled area in 2008 was 144 km^2 (Appendix 1) compared with 119–175 km^2 between 2001 and 2007, and 253–341 km^2 between 1996 and 1999. The Coromandel fishery was not surveyed in 2000.

The survey was not formally optimised to minimise the predicted c.v. of the estimate of recruited biomass for two main reasons. First, some strata were redesigned for the 2008 Coromandel survey in response to changes in the fishery performance. Second, time constraints on the survey limited the number of ways in which stations could realistically be allocated to strata. These constraints necessitated a more pragmatic approach than was used in the 1990s (e.g., Cryer & Parkinson 1999). Strata that were sufficiently close together to tackle in a single day (e.g., those around the Mercury Islands) were grouped. Up to about 20 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.

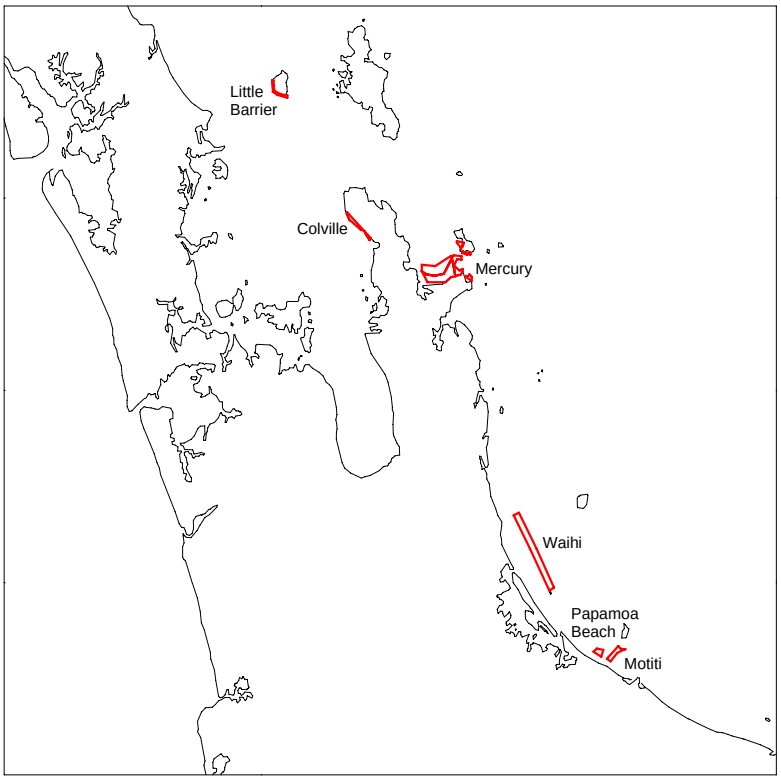

Figure 2: Location of strata for the survey of the Coromandel scallop fishery in 2008. Groups of strata are labelled with geographic descriptions used in the text (see Appendix 1 for stratum details).

Dredging in the Coromandel survey was undertaken from the chartered commercial dredge vessel *Kataraina* (whose dredge has a width of 2.0 m for which considerable historical information on dredge efficiency exists). The skipper was instructed 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 scallops or detritus, 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. Large catches were randomly subsampled for length. All unmeasured scallops were counted. No facilities for weighing the catch at each station were available to estimate the fraction sampled by weight.

3.2.2 Estimating and correcting for dredge efficiency

We used the same methodology as in the 2005–07 scallop stock assessments to estimate and correct for dredge efficiency. This approach was described in detail by Cryer & Parkinson (2006).

3.2.3 Estimating biomass at the time of survey and the start of the season

The analytical approach to estimating start-of-season recruited biomass for scallops was developed during the 2002 and 2003 stock assessments (e.g., Cryer & Parkinson 2004) and documented in detail by Cryer & Parkinson (2006). In brief, the approach contains the following nine steps.

1. The length frequency distribution for each sample is scaled according to the sampling fraction (if any).

2. The length frequency distribution for each sample is converted to "uncorrected" density per unit area of seabed, i.e., assuming the dredge to be 100% efficient for all size classes.

3. The length frequency distribution for each sample is "corrected" for dredge efficiency to estimated "real" density per unit area of seabed. These are combined to estimate the population length frequency distribution.

4. The weight (per unit area) of scallops at or above the minimum legal size (or other length of interest) is estimated using a length weight regression. Variance associated with the regression is included by bootstrapping from the raw length-weight data.

5. The mean recruited biomass (per unit area) for each stratum and for the whole population (or any subset of strata), together with the sampling variance, are estimated using bootstraps from the sampling data.

6. The absolute recruited biomass at the time of the survey is estimated by scaling the estimate of the mean biomass by the combined area of all pertinent strata. The stratum areas are considered to be without error.

7. The corrected population length frequency distribution (from step 3) is projected to the start of the forthcoming season using a growth transition matrix based on tag return data. Uncertainty about the expected average growth between survey and season is incorporated by bootstrapping, generating a new growth model for each iteration by bootstrapping from the original tag return data.

8. Mortality between survey and season is incorporated by applying an instantaneous rate of $M = 0.5\ y^{-1}$, bootstrapping (parametrically) from an estimated statistical distribution of M.

9. The absolute recruited biomass at the start of the season is estimated by repeating steps 4–6, again assuming the stratum areas to be without error.

3.2.4 2007 survey results

3.2.4.1 Coromandel fishery at the time of the survey (May 2008)

During the Coromandel survey, 17 304 of 45 623 scallops caught in 119 tows (sweeping an estimated 0.160 km^2) were measured (made up of the entire catch at 67 stations and 52 subsamples). Approximate pooled length frequency distributions corrected for dredge efficiency (by assuming historical average efficiency for each substrate type) and scaled to estimated population size were constructed for the total population of the fishery (Figure 3) and the four major fishery locations (Figure 4). By far the largest population of scallops was found at the Mercury Islands, the mainstay of the fishery, which held over 86% of the total recruited population (scallops 90 mm or more shell length). The beds at the Mercury Islands and Little Barrier Island had relatively higher proportions of large scallops than those in Hauraki Gulf (Colville) and the Bay of Plenty (off Motiti Island, Papamoa Beach, and Waihi). However, the fishery was dominated by pre-recruit scallops (smaller than 90 mm shell length), with a modal size of about 85 mm. The unusually high abundance of pre-recruits appeared to be linked to a strong cohort of scallops first observed during the May 2007 dredge survey (Williams 2008), at a modal size of about 50–60 mm. Additional sampling on 29 November 2007 at the Mercury Islands revealed this cohort had grown to about 70–80 mm (Appendix 2), and the results of the May 2008 survey suggested further growth had occurred since then.

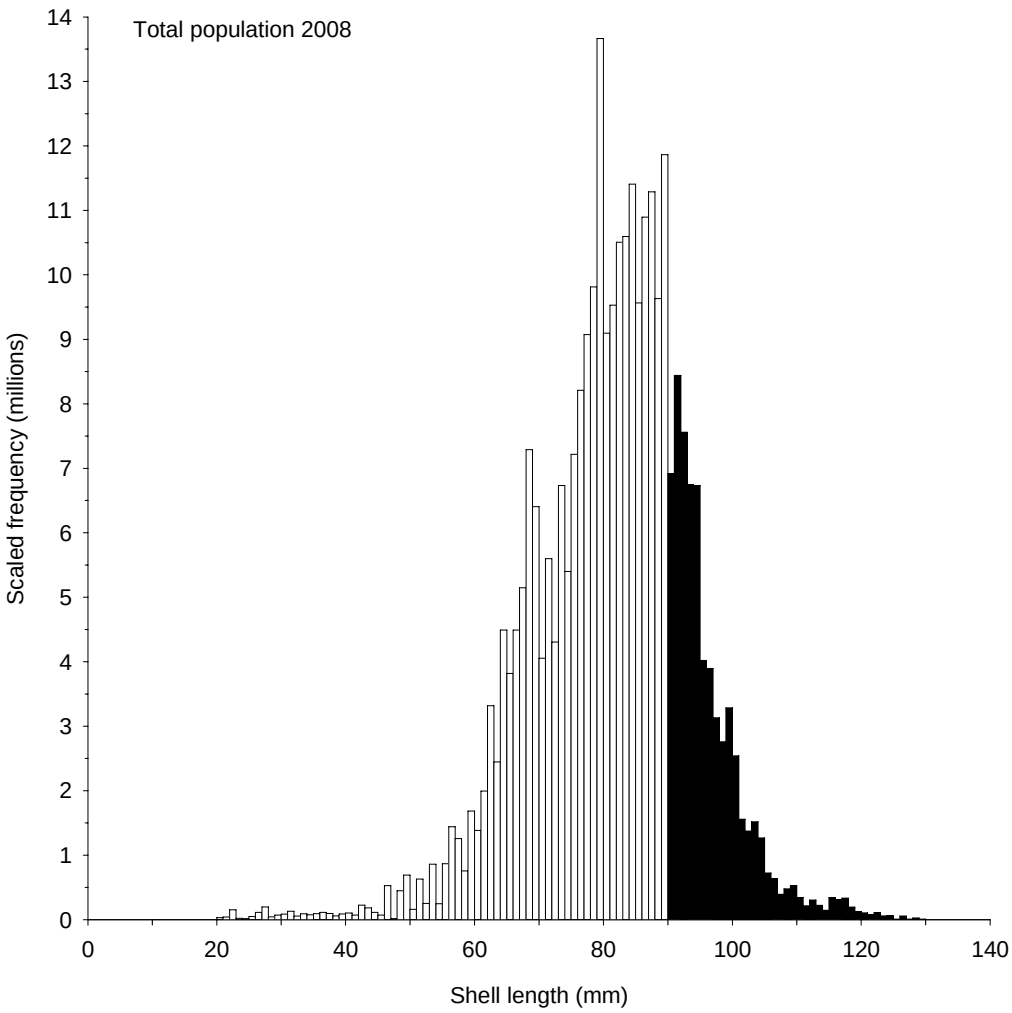

Figure 3: Length frequency distribution for the total population surveyed in the Coromandel fishery (corrected for historical average dredge efficiency), May 2008. Black bars show scallops larger than 100 mm shell length (the MLS for scallops taken commercially from the Coromandel fishery).

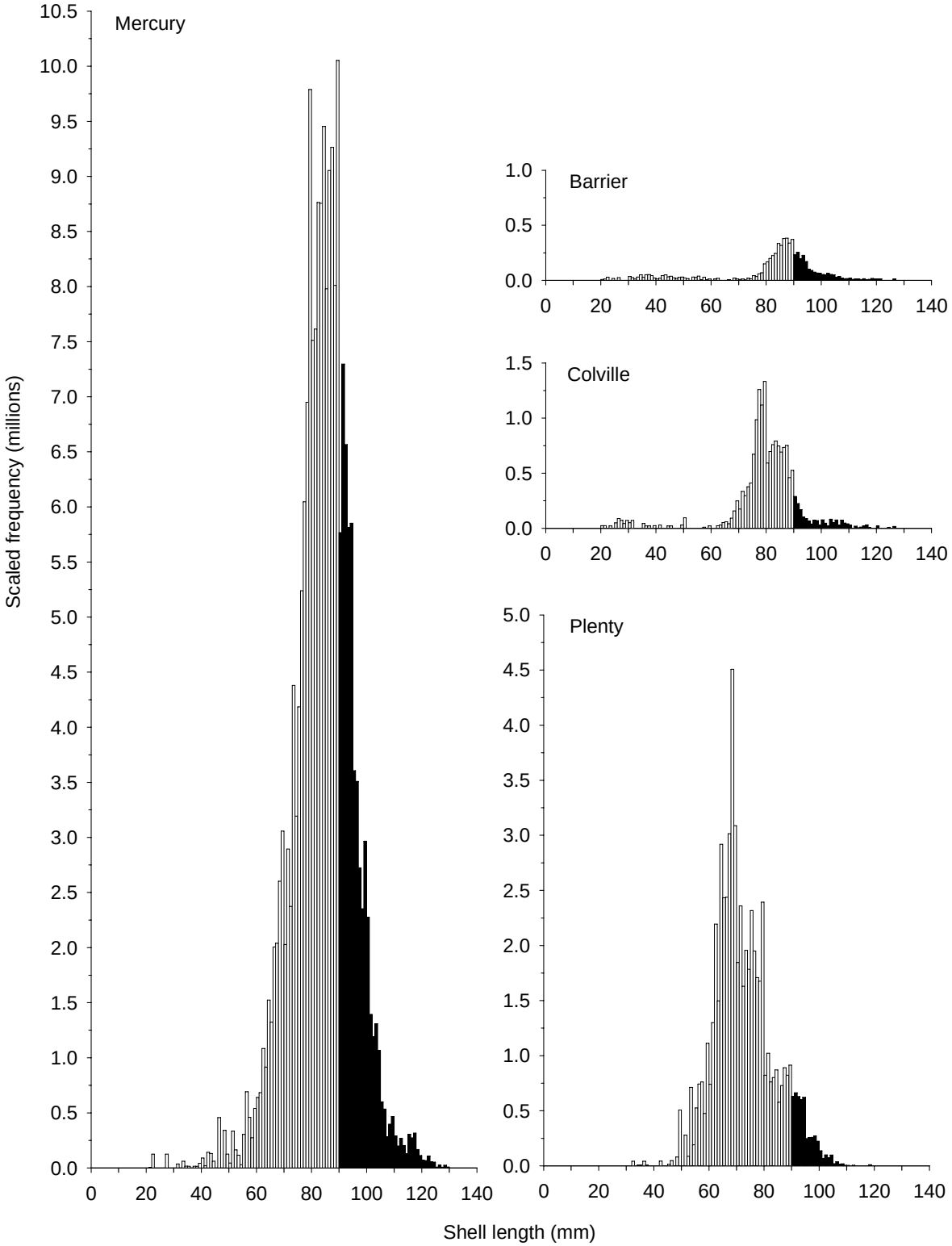

Figure 4: Length frequency distributions for the four major locations of the Coromandel fishery (corrected for historical average dredge efficiency), May 2008. Black bars show scallops larger than 100 mm shell length (the MLS for scallops taken commercially from the Coromandel fishery).

Using a simple parametric approach to estimation (including simple size-dependent scalars to correct for dredge efficiency), the biomass of scallops of 90 mm shell length or more at the time of the survey was 1274 t (no correction for dredge efficiency, Table 3) or 5415 t (corrected using historical average efficiency, Table 4) with c.v.s of 16 and 17%, respectively. These biomass estimates are reliable, but their uncertainty is grossly underestimated because this simple approach cannot incorporate additional variability associated with dredge efficiency. The biomass estimates in Table 3 (i.e., those with no correction for dredge efficiency) are the most conservative interpretation of the survey data possible and might be interpreted as the minimum absolute biomass at the time of the survey.

Table 3: Estimated density and biomass of scallops 90 mm shell length or more at the time of the Coromandel survey, assuming 100% dredge efficiency.

	Area (km^2)	Sites	Density (m^{-2})	SEM	c.v.	Millions	Mean wt. (g)	Biomass (kg m^{-2})	SEM	c.v.	Biomass (t green)
Barrier	4.2	16	0.1114	0.0246	0.22	0.46	86.87	9.68	2.10	0.22	40
Colville	7.6	12	0.0809	0.0242	0.30	0.62	81.64	6.61	1.79	0.27	50
Mercury	72.9	60	0.1818	0.0348	0.19	13.25	83.06	15.10	2.77	0.18	1101
Plenty	59.3	31	0.0178	0.0035	0.20	1.06	78.60	1.40	0.27	0.19	83
Fishery	144.0	119	0.1069	0.0177	0.17	15.39	82.81	8.85	1.41	0.16	1274

Table 4: Estimated density and biomass of scallops 90 mm shell length or more at the time of the Coromandel survey, assuming historical average dredge efficiency (but not including variance associated with dredge efficiency).

	Area (km^2)	Sites	Density (m^{-2})	SEM	c.v.	Millions	Mean wt. (g)	Biomass (kg m^{-2})	SEM	c.v.	Biomass (t green)
Barrier	4.2	16	0.4885	0.1128	0.23	2.03	83.09	40.59	9.14	0.23	169
Colville	7.6	12	0.2439	0.0677	0.28	1.86	85.72	20.90	5.12	0.24	160
Mercury	72.9	60	0.8049	0.1641	0.20	58.66	80.17	64.53	12.69	0.20	4703
Plenty	59.3	31	0.0845	0.0178	0.21	5.01	76.54	6.47	1.33	0.21	384
Fishery	144.0	119	0.4693	0.0835	0.18	67.57	80.14	37.61	6.46	0.17	5415

A more sophisticated "re-sampling" approach to variance estimation, including variability associated with the dredge efficiency scalars and length-weight regressions, produced biomass estimates very similar to those from the simple parametric approach (e.g., Table 4), but increased the c.v.s on the fishery-wide density and biomass estimates to about 25%. The statistical distribution of the 90 mm and over biomass estimate (mean = 5442 t; median = 5272 t) was slightly positively skewed (Figure 5), but not markedly so, and estimates of the c.v. were very similar whether calculated parametrically from a fitted normal distribution or non-parametrically by dividing the 95% confidence range of the bootstraps by 3.92 (1.96 * 2). Converting this estimate of greenweight biomass to meatweight would not be simple because few data are available on the average conversion factor outside the commercial season. However, conversion rates of 12.5% (the official gazetted rate) or 13.5% (historical research data) could be used, suggesting a meatweight biomass of about 680–735 t (mean values, with a c.v. of about 25%) at the time of the survey (Figure 5).

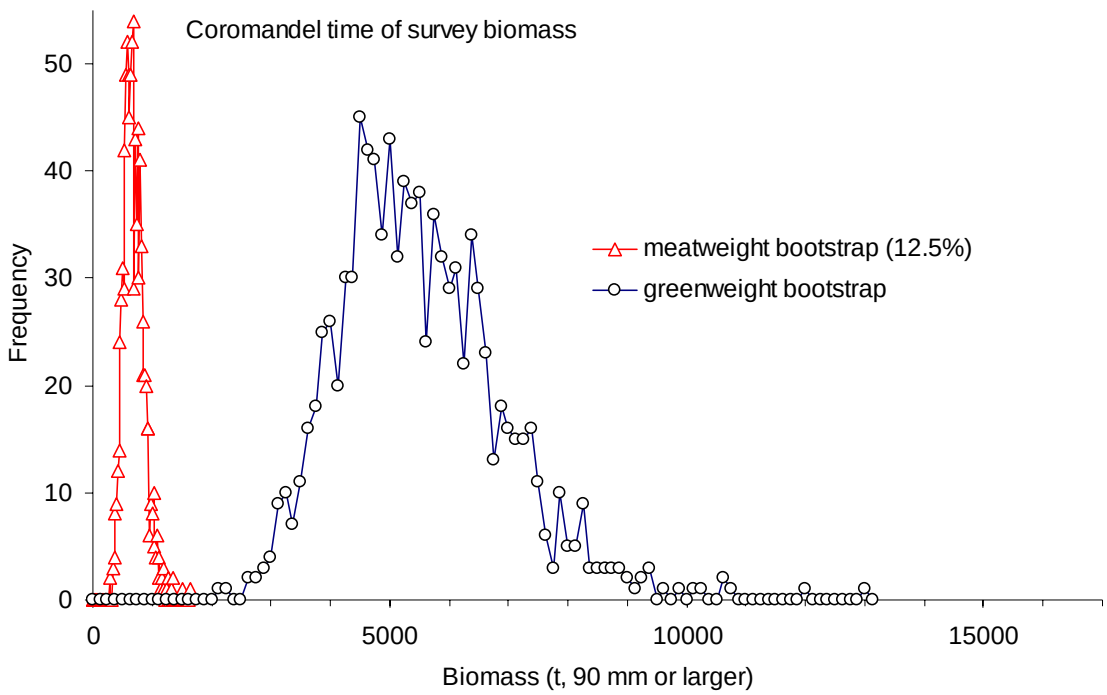

Figure 5: Frequency distributions of estimated recruited biomass (90 mm or larger) in the Coromandel fishery at the time of the survey (mid May 2008). These distributions show the results of a completely non-parametric re-sampling approach to estimating biomass (1000 bootstraps). Values are plotted in t greenweight (open circles) and meatweight (open triangles, assuming 12.5% meatweight recovery from greenweight). Both curves scaled to similar heights for clarity.

3.2.4.2 Trends in the Coromandel fishery since 1990: scallops 95 mm or more

Discerning trends in the biomass of recruited scallops is complicated by changes to survey coverage, the establishment of closed areas, and uncertainty about dredge efficiency in any particular year. However, some changes have been so large as to transcend this combined uncertainty, such as the substantial improvement observed since the turn of the century, especially at the Mercury Islands (Table 5, although this table may be slightly misleading because it is based on a size of 95 mm). In 2005, the "mainstay" of the fishery at the Mercury Islands had recovered enormously from the lowest ever recorded abundance of scallops in 2001 (53.2 million *vs*. 1.5 million scallops 95 mm or longer, Table 5), and the overall fishery abundance (Table 5) and biomass (Table 6) in 2005 was the highest ever recorded. Recruited abundance and biomass have declined since about 2005–06, although they were still high in 2008 compared with historical records.

In 2008, *Chaetopterus* tubeworms were quite rare, and were never a hindrance to surveying (they filled the dredge and caused it to "fly" in 2001). The total fishery biomass of scallops 95 mm or more in 2008 was about 54% lower than 2007, but was at about the level of the long-term average (1980 to present). This was the result of the relatively large biomass at the Mercury Islands beds being 35% above the long-term average, and the biomass in all other surveyed areas of the fishery (Little Barrier, Colville, and the Bay of Plenty) being lower than long-term average. However, there is evidence that an unusually large cohort of pre-recruits at the Mercury Islands beds could enter the fishable biomass during the 2008 season (Appendix 2).

Table 5: Estimated number of scallops (at the time of surveys) in constituent areas of the Coromandel fishery since 1990 (millions 95 mm or more shell length assuming historical average dredge efficiency applied as simple length-independent scalars for all years, including 2001–03 when different vessels were used). Totals include data from all surveyed beds and are not directly comparable among years. –, no survey in an area or year.

	Number of scallops 95 mm or larger (millions)						
Year	Little Barrier	Waiheke Island	Colville	Mercury Islands	Waihi	Motiti, Papamoa	Total
1990	–	6.4	–	7.4	–	–	13.8
1991	–	2.8	–	11.1	–	–	13.9
1992	–	0.7	–	10.7	–	–	11.4
1993	–	0.4	0.3	6.6	7.1	–	14.4
1994	–	0.0	–	4.8	1.5	–	6.3
1995	2.5	0.3	0.1	4.4	0.6	4.5	12.5
1996	3.3	0.3	0.1	6.1	0.2	2.2	12.6
1997	4.0	5.4	0.3	6.1	0.7	1.9	18.4
1998	1.0	5.3	0.2	6.4	0.1	1.2	14.2
1999	0.2	0.2	0.0	1.8	0.2	0.9	3.3
2000	–	–	–	–	–	–	–
2001	1.6	0.2	–	1.5	–	0.7	4.2
2002	0.8	1.0	–	2.7	–	0.7	5.3
2003	1.4	1.7	3.5	4.2	–	2.1	12.9
2004	1.2	4.7	0.3	23.5	1.0	2.4	33.2
2005	2.8	2.4	2.5	53.2	3.7	1.8	66.6
2006	3.1	–	6.8	46.2	0.5	2.1	58.7
2007	2.0	0.6	2.6	34.8	1.8	2.4	44.2
2008	0.7	–	0.9	18.9	0.8	0.4	21.8

Table 6: Estimated 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. Bay of Plenty estimates come from beds at Waihi, Motiti, and Papamoa; 'Other' estimates from other surveyed areas of the fishery (exclusively Colville since at least 2005). Totals include data from all surveyed beds and are not directly comparable among years. –, no survey in a given year; *, not all beds surveyed, estimate of total biomass probably significantly biased low.

	Biomass of scallops 95 mm or larger (t)					
Year	Little Barrier	Waiheke Island	Mercury Islands	Bay of Plenty	Other	Total
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	258	26	445	509	39	1 277
1996	346	28	619	241	10	1 244
1997	402	508	623	269	37	1 839
1998	99	506	641	132	36	1 414
1999	19	18	176	87	25	325
2000	–	–	–	–	–	–
2001	152	19	142	70	20	403
2002	85	90	255	70	13	513
2003	146	160	428	206	347	1 287
2004	119	471	2 546	340	3	3 479
2005	282	217	5 036	518	259	6 311
2006	321	–	4 397	237	685	5 640
2007	211	51	3 449	365	254	4 329
2008	66	–	1 743	107	88	2 004

3.2.4.3 Predicting start-of-season biomass in the Coromandel fishery

The projected biomass of scallops 90 mm shell length or more at the start of the season (15 July 2008) was estimated assuming historical average dredge efficiency at length, average growth (from previous tagging studies), and M = 0.5 spread evenly through the year. This approach produced an estimated start of season biomass of 6900 t greenweight (median projected value) with a c.v. of 28% (Table 7), thereby predicting a large increase (of about 31%) in recruited biomass between survey and season (Figure 6). Further, assuming historical average recovery of meatweight from greenweight led to an estimate of 868 t meatweight (median projected value) with a c.v. of 31% (Table 7). The average weight of a recruited scallop in Coromandel in 2008 was projected to decline from about 81 to 73 g by the start of the season (Table 7). Together, these results could be explained by the unusually large number (tens of millions) of pre-recruit scallops (just smaller than 90 mm) at the time of the survey growing into the recruited biomass by the start of the season. Further growth of pre-recruit scallops could see additional recruitment to the fishable biomass during the 2008 season.

Table 7: Mean and median projected biomass of scallops 90 mm shell length or more in the Coromandel fishery at the start of the season assuming historical average dredge efficiency at length, average growth (from previous tagging studies), M = 0.5 spread evenly through the year, and average recovery of meatweight from greenweight. Mean weights are calculated using mean values, and c.v.s are calculated assuming normality (and are, therefore, very approximate).

	Surveyed area	Millions of scallops		Scallop weight (g)	Greenweight biomass (t)			Meatweight biomass (t)		
	(km^2)	Mean	Median	Mean	Mean	Median	c.v.	Mean	Median	c.v.
Barrier	4.2	2.92	2.79	75.38	220	211	0.30	28	27	0.34
Colville	7.6	3.79	3.36	71.32	270	244	0.49	34	31	0.51
Mercury	72.9	82.80	79.69	73.61	6 095	5 893	0.30	776	741	0.34
Plenty	59.3	7.33	6.91	70.54	517	490	0.31	65	62	0.35
Fishery	144.0	96.83	94.04	73.34	7 102	6 900	0.28	903	868	0.31

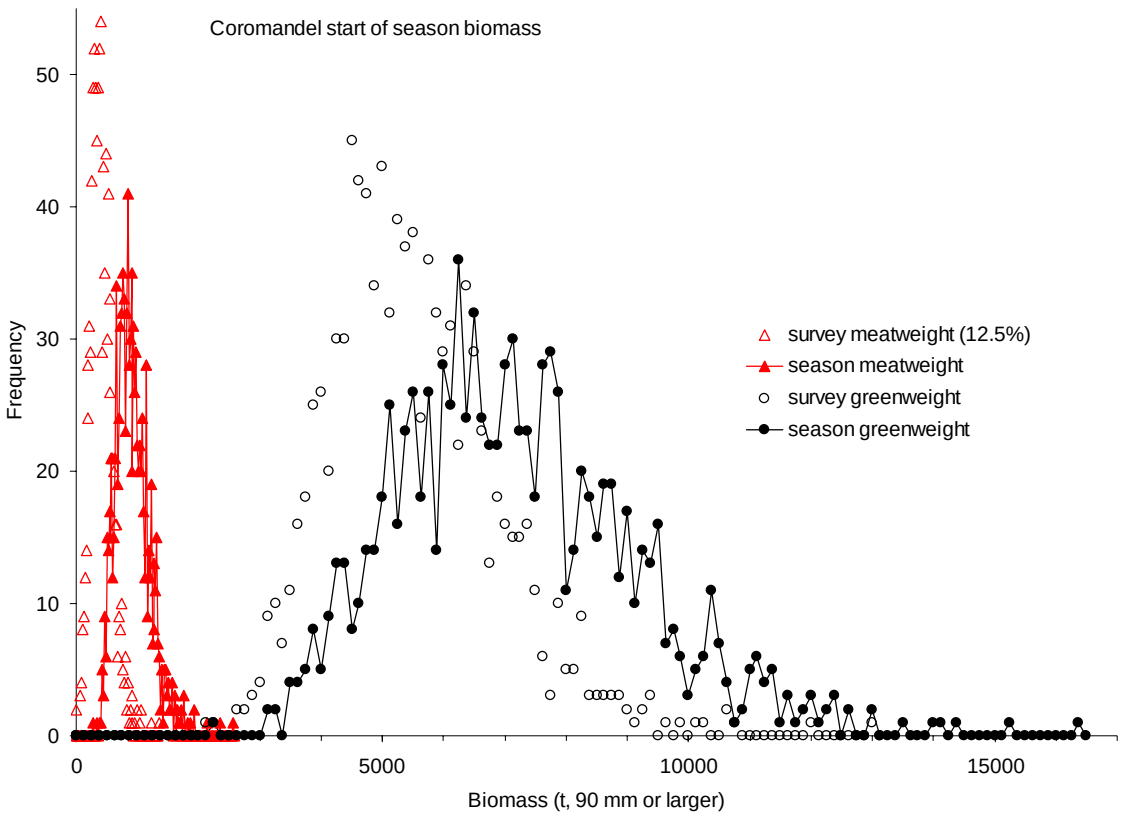

Figure 6: Frequency distributions of estimated recruited biomass (90 mm or larger) in the Coromandel fishery at the start of the season (mid July 2008). The results of a completely non-parametric re-sampling and projection approach are shown for the start of the season in t greenweight (closed circles) and meatweight (closed triangles). Symbols with no joining line show the results of the time of survey analysis in t greenweight (open circles) and approximate meatweight (open triangles, assuming 12.5% recovery of meatweight from greenweight). All curves scaled to similar heights for clarity.

3.3 Biomass estimates

Estimates of current (2008) biomass are described above; the recruited biomass of scallops 90 mm in shell length or greater at the start of the 2008 season in the Coromandel fishery was predicted to be 6900 t (greenweight) and 868 t (meatweight) (median projected values; Table 7). Given the highly variable nature of scallop populations, the concept of virgin biomass is probably not meaningful, but average (recruited) biomass could be estimated from the data presented in the tables.

3.4 Yield estimates

3.4.1 Reference rates of fishing mortality

Yield estimates are generally calculated using reference rates of fishing mortality applied in some way to an estimate of current or reference biomass. Cryer & Parkinson (2006) reviewed reference rates of fishing mortality and summarised modelling studies by Cryer & Parkinson (1997) and Cryer et al. (2004). The Ministry of Fisheries Shellfish Working Group recommend $F_{0.1}$ as the most appropriate reference rate of fishing mortality for scallops.

3.4.2 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. Cryer et al. (2003) showed that constant catch strategies for scallops produced lower yield at much higher biological risk than strategies wherein catch was varied as biomass varied.

3.4.3 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):

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

where F_{ref} is a reference fishing mortality ($F_{0.1}$) and B_{jul} is the start-of-season (15 July) recruited biomass (scallops of 90 mm or more shell length). The equation above is specific to the five month Coromandel scallop fishing season. B_{jul} was estimated assuming historical average dredge efficiency at length, average growth (from previous tagging studies), M = 0.5 spread evenly through the year, and historical average recovery of meatweight from greenweight.

Modelling studies (Cryer et al. 2004, Cryer & Morrison 1997) indicate that $F_{0.1}$ is sensitive not only to the direct incidental effects of fishing (reduced growth and increased mortality on essentially adult scallops), but also to indirect incidental effects (such as additional juvenile mortality related to reduced habitat heterogeneity in dredged areas). Consequently, CAY was calculated for two scenarios:

1) CAY including direct effects on adults

By including only the direct incidental effects of fishing on scallops, Cryer et al. (2004) derived an estimate of $F_{0.1}$ = 0.431. Using this value and the 2008 start of season biomass estimates (median projected values), CAY was estimated to be 2197 t greenweight or 276 t meatweight.

2) CAY including direct and indirect effects on adults and juveniles

Cryer et al. (2004) modelled the "feedback" effects of habitat modification by the dredge method on juvenile mortality in scallops. They developed estimates of F_{ref} that incorporated such effects, but had to make assumptions about the duration of what they called the "critical phase" of juvenile growth during which scallops were susceptible to increased mortality. To give some guidance on the possible outcome of including "indirect" (as well as direct) effects on yield estimates, Cryer et al.'s (2004) estimate of $F_{0.1}$ = 0.274 was applied here. Using this value and the 2008 start of season biomass estimates (median projected values), CAY was estimated to be 1500 t greenweight or 189 t meatweight.

For both scenarios, the estimates of CAY would have c.v.s at least as large as those of the estimates of start-of-season recruited biomass (28–31%), are sensitive to assumptions about dredge efficiency, growth, and expected recovery of meatweight from greenweight, and relate to the surveyed beds only. There is also additional uncertainty associated with using a point estimate of $F_{0.1}$ (i.e., variance associated with the point estimate of $F_{0.1}$ was not incorporated in the analysis). Further, the second approach which includes indirect incidental effects (putative "habitat effects") is sensitive to the duration of any habitat-mediated increase in juvenile mortality.

3.4.4 Confronting uncertainty in CAY

Regardless of the approach used to estimate CAY, the production of a single 'best estimate' of CAY should be treated with caution: it should certainly not be viewed as the 'true' CAY because it is only one in a range of possible estimates (Figure 7). Instead, it would be more appropriate to convert the statistical distribution of CAY to a cumulative frequency distribution, which can be interpreted as the probability of exceeding the true CAY (Figure 8). For example, if catch limits were set at the level of our best estimate of CAY (e.g., 276 t meatweight, excluding putative habitat effects) there would be a 50% chance of exceeding the true CAY (of course, there would also be a 50% chance of being lower than the true CAY). In contrast, if catch limits were set to, say, 150 t, the probability of exceeding the true CAY would be less than 5%. In this way the level of risk to the putative Coromandel scallop stock of fishing at a variety of potential catch limits can be assessed (Table 8).

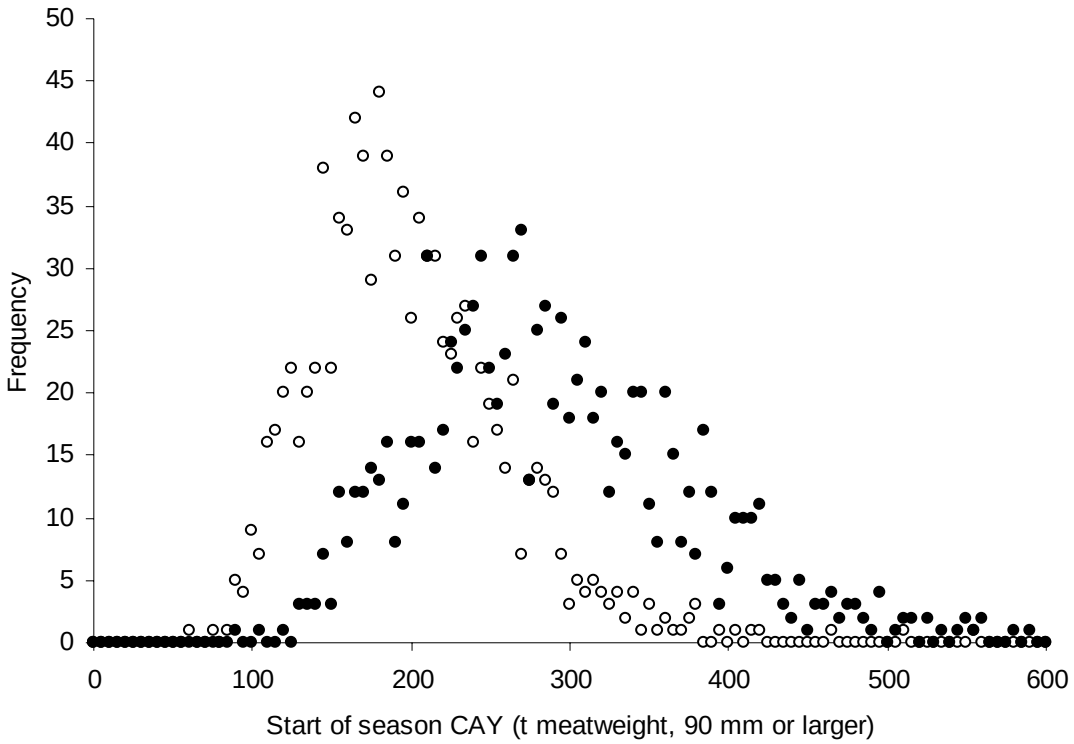

Figure 7: Frequency distribution of Current Annual Yield (90 mm or larger) in the Coromandel fishery at the start of the season (15 July 2008). CAY was estimated using two approaches: excluding (solid circles) and including (open circles) putative habitat effects.

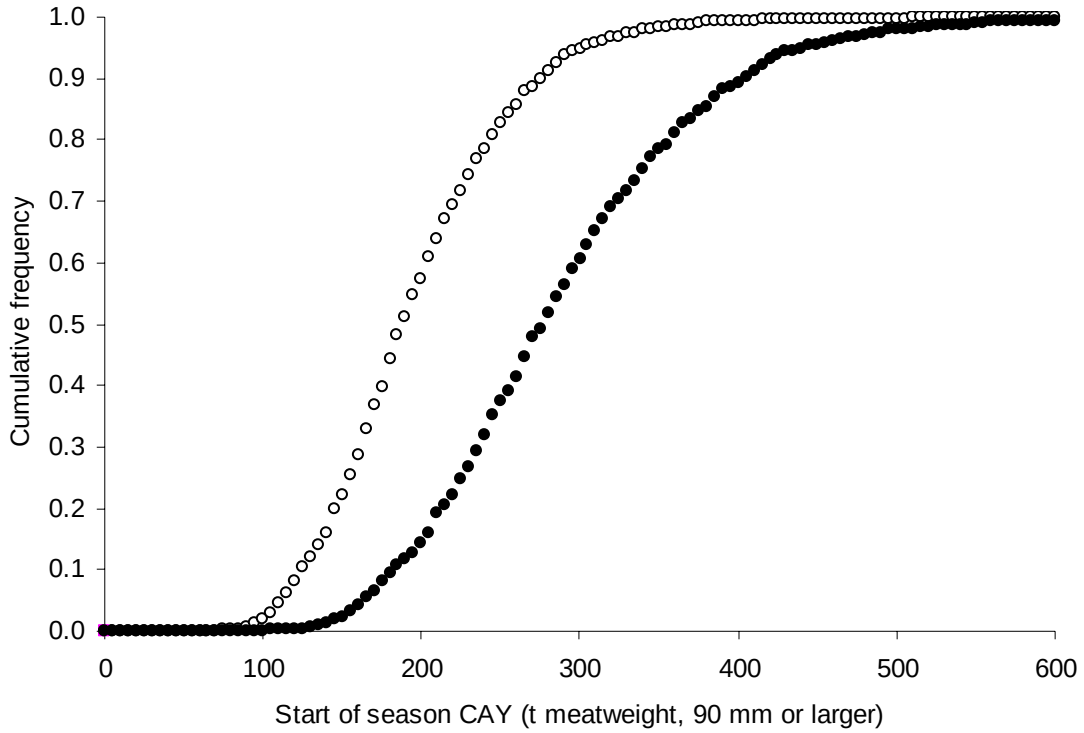

Figure 8: Cumulative frequency distribution of Current Annual Yield (90 mm or larger) in the Coromandel fishery at the start of the season (15 July 2008). CAY was estimated using two approaches: excluding (solid circles) and including (open circles) putative effects.

Table 8: Decision table to evaluate the 'risk' of exceeding the 'true' CAY given a variety of alternative catch limits. CAY was estimated using two approaches: excluding and including putative habitat effects.

Potential TACC catch limit for 2008–09 (t meatweight)	Probability of exceeding CAY	
	Excluding habitat effects	Including habitat effects
275	0.492	0.899
250	0.373	0.827
225	0.246	0.717
200	0.144	0.574
175	0.080	0.398
150	0.022	0.221
125	0.003	0.103
100	0.001	0.021

3.4.4 Estimation of Provisional Yield

Until 1997, stock assessments for northern scallop fisheries were based on Provisional Yield (PY), 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 (Cryer 1994). Experiments and modelling showed this method to be suboptimal, however. Provisional Yield is no longer accepted as appropriate, and stock assessments since 1998 have used a CAY approach.

4. MANAGEMENT IMPLICATIONS

Estimates of current biomass for the Coromandel fishery are available from the 2008 dredge 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 (2000) 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 was assumed about dredge efficiency) was the highest on record and probably higher than in the mid 1980s 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 (Figures 9–11). There has been a decline in the overall biomass since about 2005–06, and the biomass in 2008 was at about the level of the long term average (1980 to present). Most (about 86%) of this biomass was held in the Mercury Islands beds (the mainstay of the fishery); biomass in this area remains high compared with historical records (about 35% above the long term average).

Substantial uncertainty stemming from assumptions about dredge efficiency during the survey, rates of growth and natural mortality between survey and season, and predicting the average recovery of meatweight from greenweight remain in these stock assessments. Future research should be aimed at reducing this uncertainty, and could include a modelling study of dredge efficiency using existing data, and more field studies of scallop growth and mortality. Managing the fisheries based on the number of recruited scallops at the start of the season, as opposed to recruited biomass (the current approach), could remove the uncertainty associated with converting estimated numbers of scallops to estimated meatweight.

We do not understand the processes that have resulted in such large fluctuations in scallop abundance. To get sustainable yield from such a variable stock it is necessary to alter the catch every year. Recent management of Coromandel scallops has been based on a Current Annual Yield (CAY) approach using $F_{0.1}$ as a suitable reference rate of fishing mortality, which is considered both appropriate and conservative. Annual pre-season research surveys are required to estimate recruited biomass and for stock assessment to estimate CAY. Commercial catch limits are adjusted each survey year following a review of the survey results and stock assessment, and after consultation with fishery stakeholders.

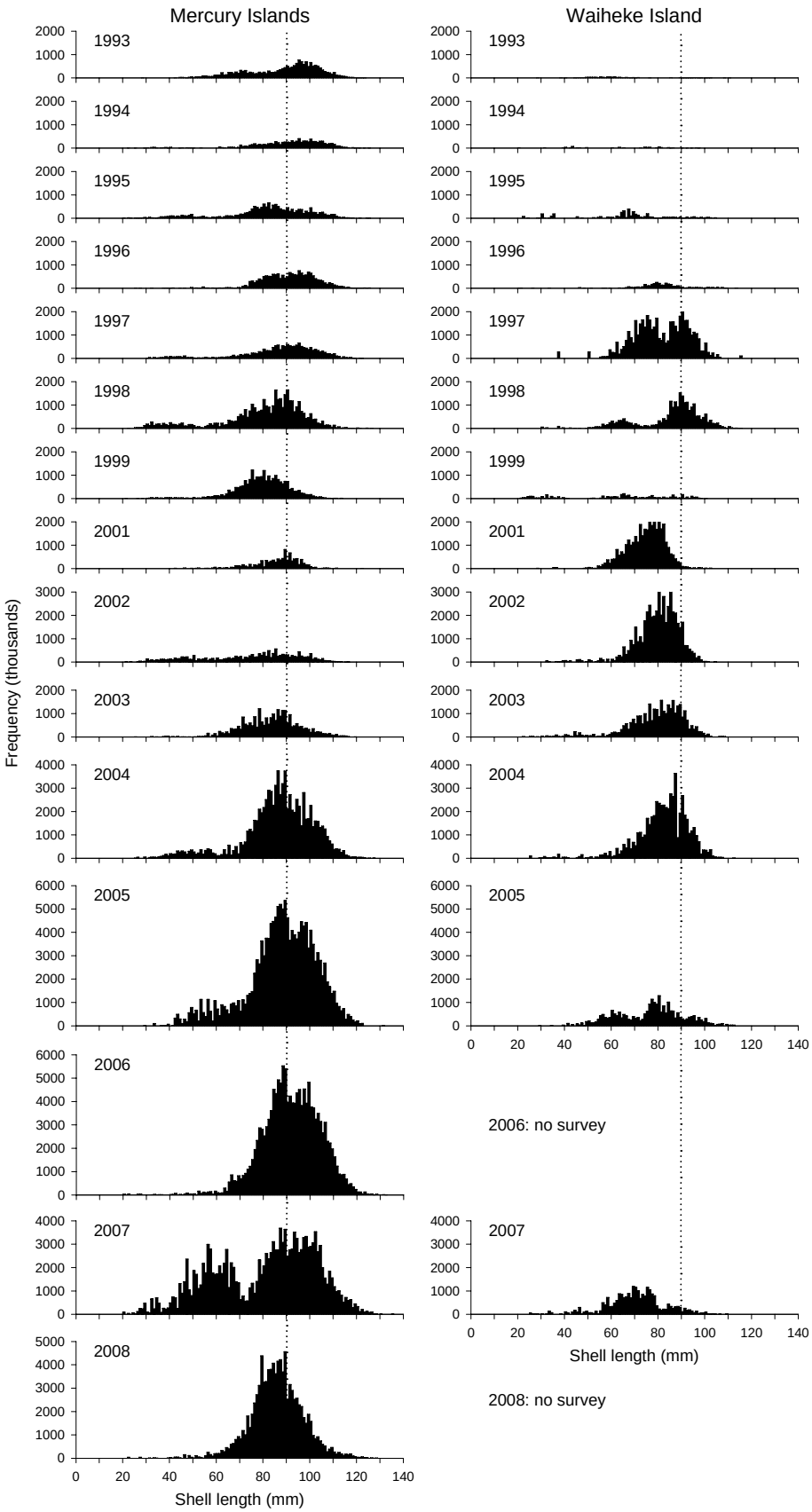

Figure 9: Scaled length frequency distributions at the time of surveys estimated using historical average dredge efficiency for scallops in the Coromandel fishery at the Mercury Islands (left) and Waiheke Island (right) since 1993. There were no surveys in 2000, and the Waiheke Island stratum was not surveyed in 2006 or 2008. Vertical dotted lines indicate the minimum legal size of 90 mm shell length.

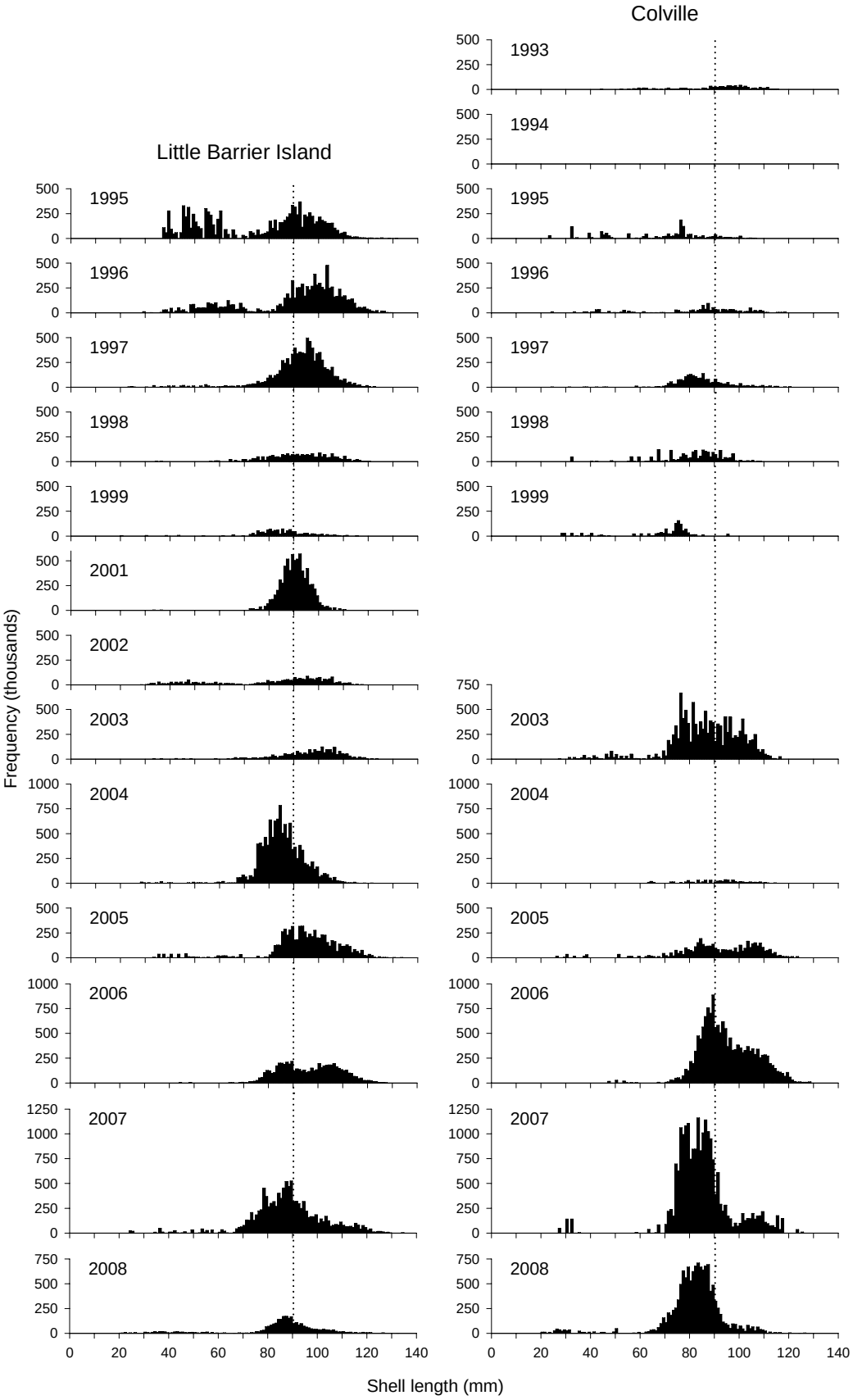

Figure 10: Scaled length frequency distributions at the time of surveys estimated using historical average dredge efficiency for scallops in the Coromandel fishery at Little Barrier Island (left) and Colville (right) since 1993. The fishery was not surveyed in 2000, and Colville was not surveyed in 2001 and 2002. Vertical dotted lines indicate the minimum legal size of 90 mm shell length.

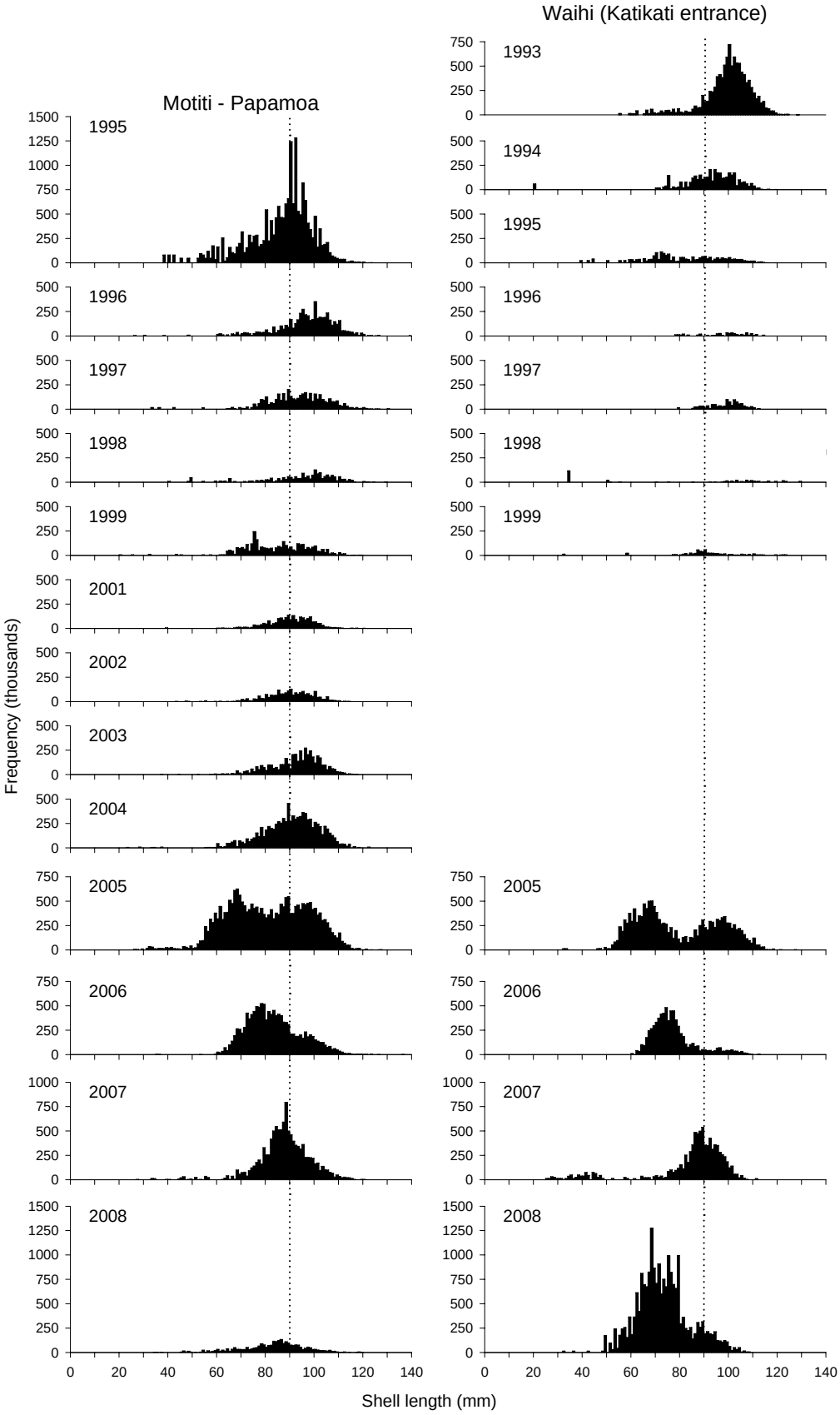

Figure 11: Scaled length frequency distributions at the time of surveys estimated using historical average dredge efficiency for scallops in the Coromandel fishery at Motiti-Papamoa (left) and Waihi (right) since 1993. The fishery was not surveyed in 2000, and Waihi was not surveyed between 2000 and 2004. Vertical dotted lines indicate the minimum legal size of 100 mm shell length.

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6. REFERENCES

Boyd, R.O.; Gowing, L.; Reilly, J.L. (2004). 2000-2001 national marine recreational fishing survey: diary results and harvest estimates. Final Research Report for Ministry of Fisheries project REC2000/03. 81 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Boyd, R.O.; Reilly, J.L. (2002). 1999/2000 national marine recreational fishing survey: harvest estimates. Final Research Report for Ministry of Fisheries project REC98/03. 28 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Bradford, E. (1997). Estimated recreational catches from Ministry of Fisheries North region marine recreational fishing surveys, 1993-94. New Zealand Fisheries Assessment Research Document 97/7. 16 p. (Unpublished report held in NIWA library, Wellington.)

Bradford, E. (1998). Harvest estimates from the 1996 national marine recreational fishing surveys. New Zealand Fisheries Assessment Research Document 98/16. 27 p. (Unpublished report held in NIWA library, Wellington.)

Bull, M.F. (1988). New Zealand scallop. New Zealand Fisheries Assessment Research Document 88/25. 16 p. (Unpublished report held in NIWA library, Wellington.)

Caddy, J.F.; Gulland, J.A. (1983). Historical patterns of fish stocks. *Marine Policy 7(4)*: 267–278.

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 94/18. 21 p. (Unpublished report held in NIWA library, Wellington.)

Cryer, M. (2001). 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.; Breen, P.A.; Kendrick, T.H. (2003). Models to evaluate fishing strategies for northern scallop fisheries. Final Research Report for Ministry of Fisheries project MOF2000/03E. 61 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Cryer, M.; Davies, N.M.; Morrison, M. (2004). Collateral damage in scallop fisheries: translating "statistics" into management advice. Presentation and working document for Shellfish Fishery Assessment Working Group, March 2004. 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 Research Report for Ministry of Fisheries project AKSC03. 32 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Cryer, M.; Parkinson, D.M. (1999). Dredge surveys and sampling of commercial landings in the Northland and Coromandel scallop fisheries, 1998. *NIWA Technical Report 69*. 63 p.

Cryer, M.; Parkinson, D.M. (2004). Dredge survey and stock assessment for the Coromandel scallop fishery, 2004. Final Research Report for 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.

MAF Fisheries (1990). RAND_STN v 1.7 implementation for PC computers. p.

Ministry of Fisheries Science Group (Comps.) (2006). Report from the Fishery Assessment Plenary, May 2006: stock assessments and yield estimates. 875 p. (Unpublished report held in NIWA library, Wellington.)

Morrison, M.A. (1997). Population dynamics and exploitation of scallops, *Pecten novaezelandiae*, in the Hauraki Gulf. Unpublished PhD thesis. University of Auckland, New Zealand. 157 p.

Orensanz, J.M.; Parma, A.M.; Iribarne, O.O. (1991). Population dynamics and management of natural stocks. *In*: Shumway, S.E. (ed.). Scallops: biology, ecology and aquaculture, pp. 625–713. Elsevier, Amsterdam.

Shumway, S.E.; Sandifer, P.A. (eds). (1991). Scallop biology and culture: an international compendium.World Aquaculture Workshops, No 1, 1991. (Includes 47 papers from the 7th International Pectinid Workshop, April 1989, Portland, Maine.) World Aquaculture Society, Baton Rouge, Louisiana, USA. 357 p.

Williams, J.R. (2005). Reproductive ecology of the scallop *Pecten novaezelandiae*. Unpublished PhD thesis. University of Auckland, New Zealand. 134 p.

Williams, J.R. (2008). Biomass surveys and stock assessments for the Coromandel and Northland scallop fisheries, 2007. *New Zealand Fisheries Assessment Report 2008/35*. 41 p.

Williams, J.R.; Babcock, R.C. (2004). Comparison of multiple techniques to evaluate reproductive variability in a marine bivalve: application to the scallop *Pecten novaezelandiae*. *Marine and Freshwater Research 55(5)*: 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(4)*: 851–864.

APPENDIX 1

Stratum definitions and station (tow) allocations, Coromandel scallop survey 2008. After detailed consultation with fishers, only areas expected to contain commercial densities of scallops and be amenable to fishing were included. Areas closed to commercial fishing were excluded.

Location	Stratum name	Code	Area (m^2)	Substrate	# stations	Stations/km^2
Little Barrier Island	Little Barrier West	18	1 361 542	sand	6	4.41
	Little Barrier South	19	2 802 673	sand	10	3.57
Colville	Colville South (shallow)	31	7 634 644	mud/silt	12	1.57
Mercury Islands	Mercury Cove	4	2 840 945	mud/silt	4	1.41
	Three Mile Bank	2	4 924 946	sand	8	1.62
	Bumper Cove	43	1 210 602	sand	4	3.30
	Kennedy	41	28 523 438	sand	14	0.49
	Blackjack	1	28 298 340	sand	20	0.71
	Sarah's Gully	42	5 186 157	sand	6	1.16
	Opito Bay	3	1 896 500	sand	4	2.11
Bay of Plenty	Waihi (Katikati entrance)	11	47 210 938	sand	12	0.25
	Papamoa Beach	14	4 505 615	sand	8	1.78
	Motiti (The Knoll)	13	7 580 078	sand	11	1.45
Total	13 strata	–	143 976 418	–	119	0.83

APPENDIX 2

End of season dredge survey, 29 November 2007

Introduction

Toward the end of the 2007 Coromandel scallop season, commercial fishers jointly agreed to stop fishing early (at the end of November rather than December) because of concerns about the unusually large number of pre-recruit scallops they were catching. Stopping fishing would protect these scallops from potential damage by dredging, with the view that they could survive and grow into the recruited biomass for the 2008 season. At the fishers' request, NIWA agreed to conduct some limited dredge sampling to survey the abundance and size frequency of scallops at the end of the season.

Methods

The end of season dredge sampling was conducted at two survey strata, Three Mile Bank and Blackjack, at the Mercury Islands beds on 29 November 2007. We used the same vessel, skipper, and sampling methodology as in the full pre-season Coromandel scallop dredge survey in mid May 2007 (Williams 2008). A total of five stations (three tows at Three Mile Bank and two tows at the eastern end of Blackjack) were completed at positions close to five of the stations originally surveyed in the May 2007 survey. This allowed a comparison of the abundance and size frequency of scallops at these station positions in mid May 2007 and at the end of November 2007. For further comparison, we also conducted two 'repeat' dredge tows at the Blackjack positions at the end of (and additional to) the May 2008 Coromandel dredge survey (present study), and selected three of the randomly allocated Three Mile Bank stations from the May 2008 survey (present study) that were close to the positions of interest. Counts of scallops of any given size at each station were converted to density per square metre of seabed according to the fraction of the catch sampled, the area swept by the dredge, and assuming historical average dredge efficiency.

Results and discussion

Length frequency distributions were constructed for the three sampling times (May 2007, November 2007, and May 2008) for each of the five station positions sampled (Figure A2.1), and for all five station positions combined (Figure A2.2). The scallop population in May 2007 was clearly bimodal, with all five stations showing evidence of a strong cohort of juvenile scallops, with a modal size of about 50–60 mm shell length, and a mode of larger scallops (about 80 mm or more). This juvenile cohort was the strongest such cohort ever recorded for the Mercury Islands beds (see Figure 9). The population of scallops sampled on 29 November 2007 at the end of the season comprised a single mode of broad size range, but generally about 70–80 mm shell length. This shift in the modal size of scallops suggests the numerous juveniles observed in May 2007 had grown into adults by November. In addition to showing the high densities of pre-recruit scallops present, the limited sampling on 29 November also revealed there were still good numbers of recruited scallops (over 90 mm shell length) at the end of the season, many of which were in good meatweight condition (i.e., had large, 'ripe' gonads). In May 2008, the modal size of scallops at the five positions sampled was just under 90 mm shell length, suggesting the strong cohort had grown further since November 2007 and was starting to recruit to the fishable population for the 2008 season, as previously hoped by commercial fishers. Further survival and growth of this cohort could see significant additional recruitment to the fishable biomass during 2008.

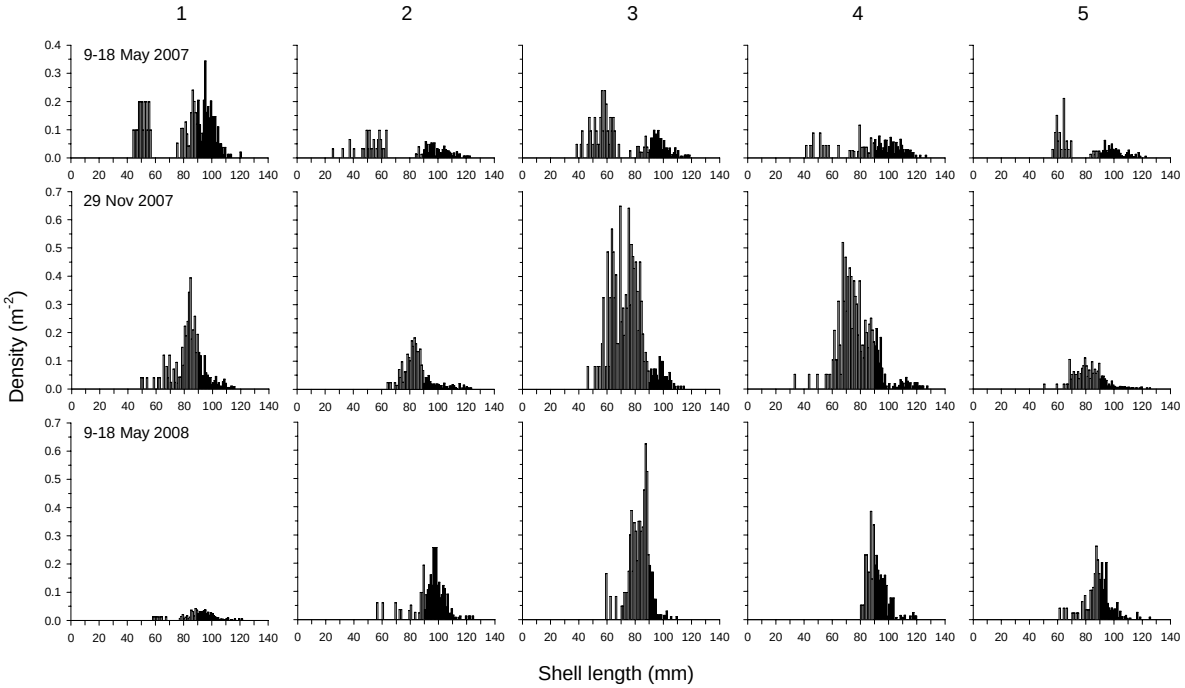

Figure A2.1: Length frequency distributions for scallops at five stations sampled at the Mercury Islands beds in mid May 2007, on 29 November 2007, and in mid May 2008. Densities have been corrected for the fraction of the catch sampled, area towed, and historical average dredge efficiency. Black bars show scallops larger than 100 mm shell length (the MLS for scallops taken commercially from the Coromandel fishery). 1–3, stations at Three Mile Bank; 4 and 5, stations at Blackjack.

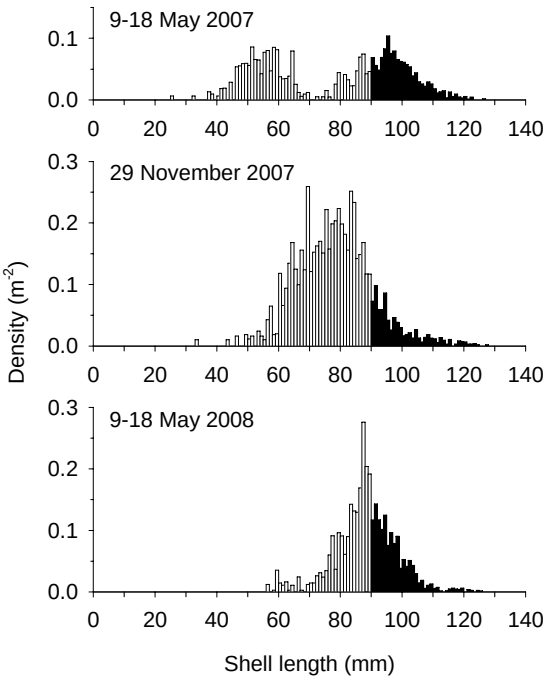

Figure A2.2: Combined length frequency distributions for scallops at five stations sampled at the Mercury Islands beds (Three Mile Bank and Blackjack strata) in mid May 2007, on 29 November 2007, and in mid May 2008. Densities have been corrected for the fraction of the catch sampled, area towed, and historical average dredge efficiency. Black bars show scallops larger than 100 mm shell length (the MLS for scallops taken commercially from the Coromandel fishery).