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EXECUTIVE SUMMARY

Cryer, M.; Parkinson, D.M. (2002). Dredge surveys of scallops in the Northland and Coromandel scallop fisheries, 2001. *New Zealand Fisheries Assessment Report 2002/61*. 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 precautionous 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.

1. 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* 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* is not known, despite anecdotal reports that scallops do not survive where *Chaetopterus* 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.

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

2.1 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 serious delay 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.

2.2 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), Stephenson 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 km² (compared with 553–714 km² 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 km² (compared with 253–341 km² in 1996–99; Figure 2, Appendix 2).

2.3 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.

2.4 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, 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 on to 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.

2.5 Assumptions about dredge efficiency

Dredges are not 100% effective at retaining scallops and efficiency can vary widely (e.g., Allan 1984, 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.

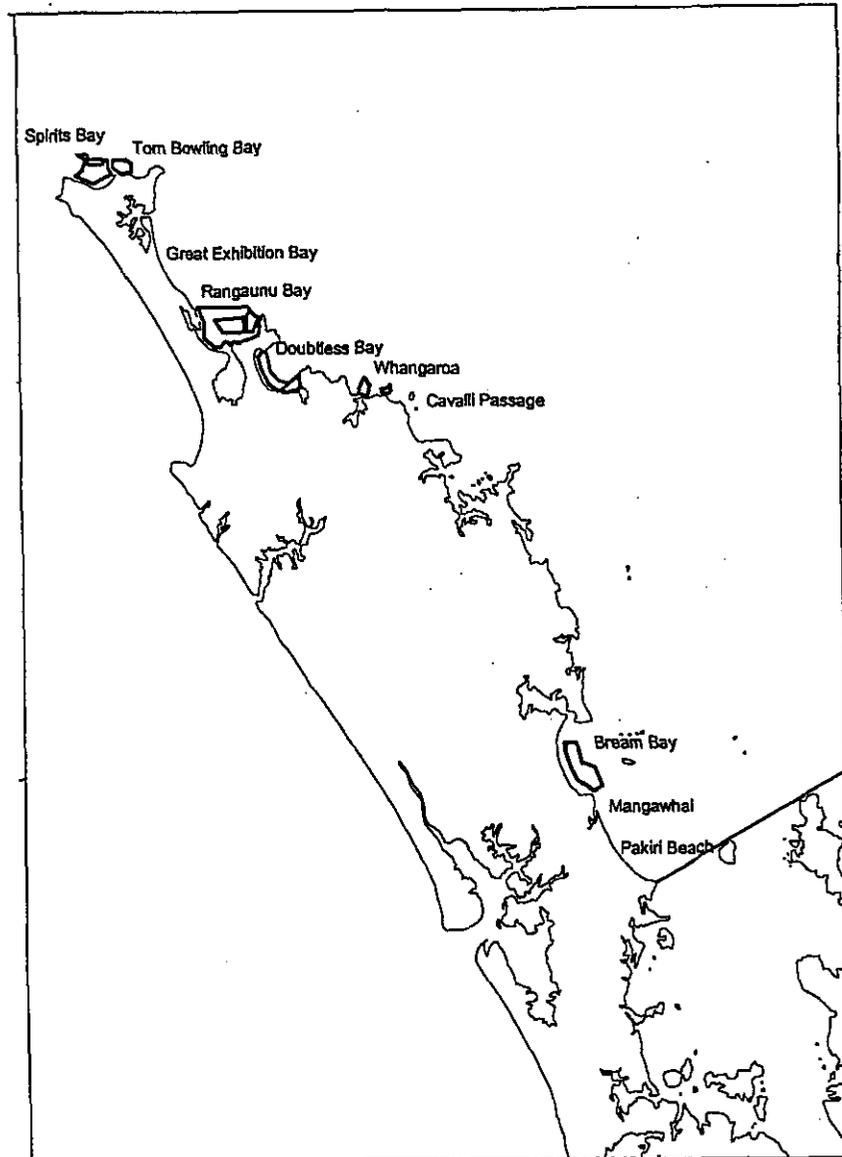


Figure 1: Location of strata for the survey of the Northland scallop fishery in 2001. Groups of strata are labelled with geographic descriptions used in the text (see Appendix 1 for details and stratum areas).

2.6 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.

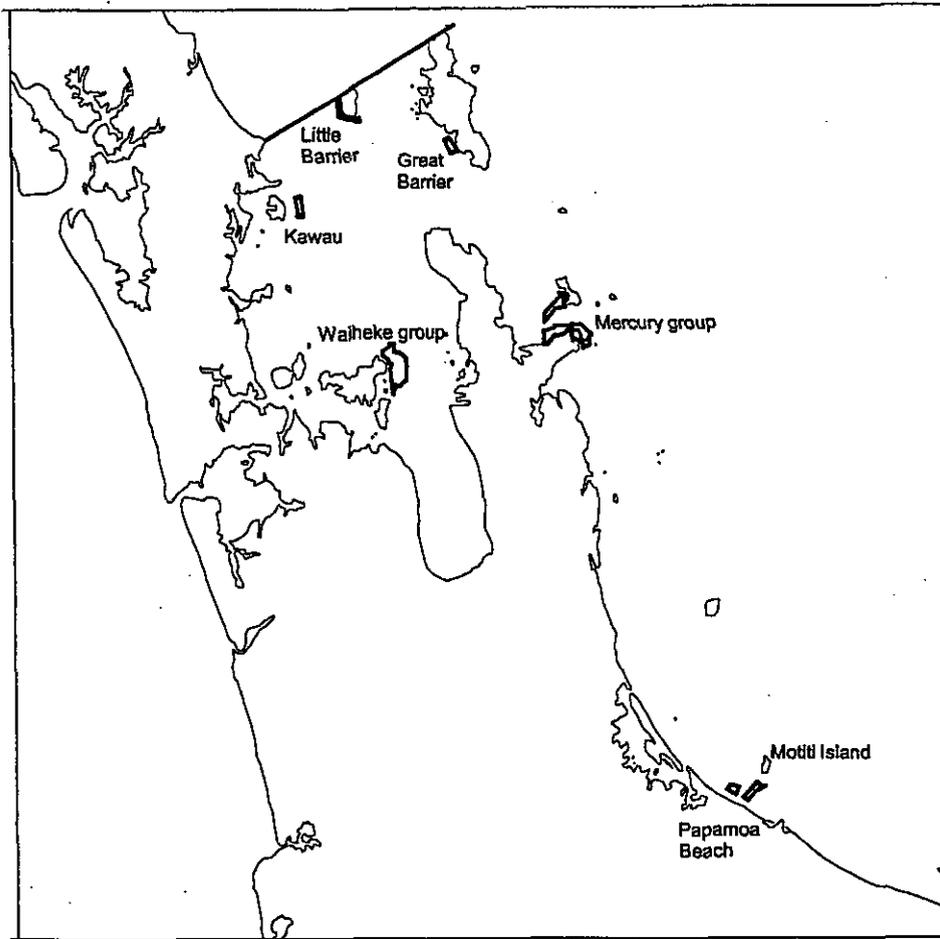


Figure 2: Location of strata for the survey of the Coromandel scallop fishery in 2001. Groups of strata are labelled with geographic descriptions used in the text (see Appendix 2 for details and stratum areas).

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.

	Sandy substrates			Silty substrates		
	Efficiency	Multiplier	c.v.	Efficiency	Multiplier	c.v.
Northland fishery						
No scaling	100.0	1.000	0.000	—	—	—
Highest historical	94.9	1.054	0.200	—	—	—
Upper 95% limit	78.4	1.276	0.200	—	—	—
Historical average	63.7	1.570	0.097	—	—	—
Coromandel fishery						
No scaling	100.0	1.000	0.000	100.0	1.000	0.000
Highest historical	77.0	1.300	0.200	70.0	1.431	0.200
Upper 95% limit	51.6	1.938	0.200	45.3	2.207	0.200
Historical average	41.0	2.437	0.102	32.3	3.096	0.144

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

2.7 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 1999) 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)

$$s^2_{(y)} = \sum A_i^2 \cdot S_i^2 \cdot (1 - \phi_i) / n_i \quad (1)$$

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, $(1 - \phi_i)$, 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 over 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):

$$N_{total} = \sum N_j \cdot E_j \quad (2)$$

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):

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

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, \bar{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)):

$$B_{recruited} = \sum N_j \cdot E_j \cdot \bar{W}_j \cdot e^{-(t \cdot M)} \quad (4)$$

where M is an assumed instantaneous rate of natural mortality ($M = 0.50 \text{ y}^{-1}$, 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)):

$$W = 0.00042 L^{2.662} \quad (5)$$

where W is the greenweight (g) and L the maximum shell length (mm, $n = 861$). The \bar{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)).

$$\bar{W}_j = \frac{\sum W_{l,j} \cdot N_{l,j}}{\sum N_{l,j}} \quad (6)$$

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):

$$\hat{B}_{recruited} = \sum (N_j + \varepsilon_{n,j}) \cdot (E_j + \varepsilon_{e,j}) \cdot \bar{W}_j \cdot e^{-(LM)} \quad (7)$$

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.

2.8 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.

3. RESULTS

3.1 Pooled length frequency distributions

In the Northland survey, 4977 of the 7346 scallops caught in 77 tows (covering 0.13 km²) were measured, compared with 5188 of the 12 666 caught in 83 tows (covering 0.13 km²) 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).

3.2 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.

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 more 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

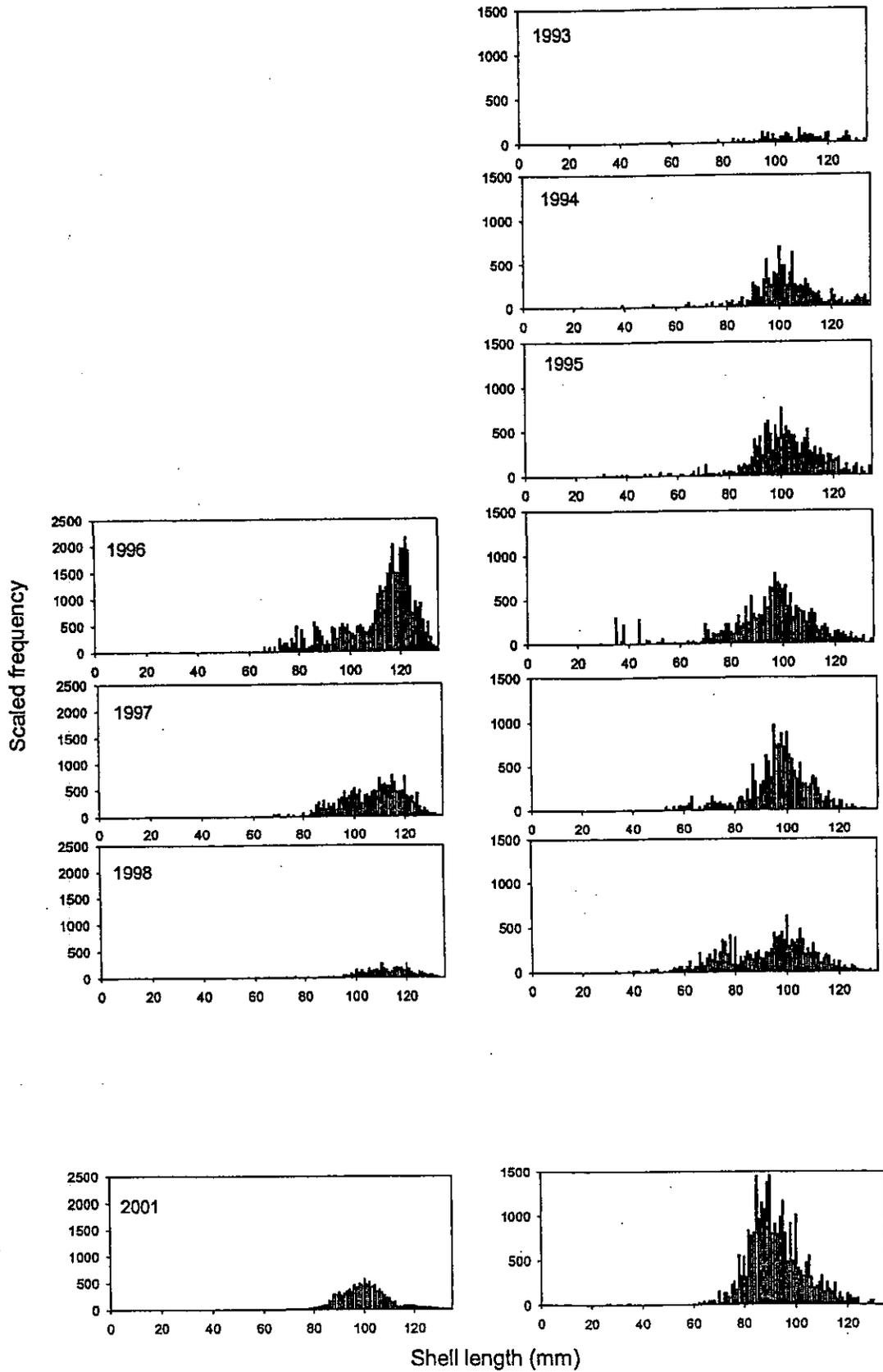


Figure 3: Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Spirits Bay and Tom Bowling Bay; right panel, Rangaunu Bay and Doubtless Bay. There were no surveys in Spirits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

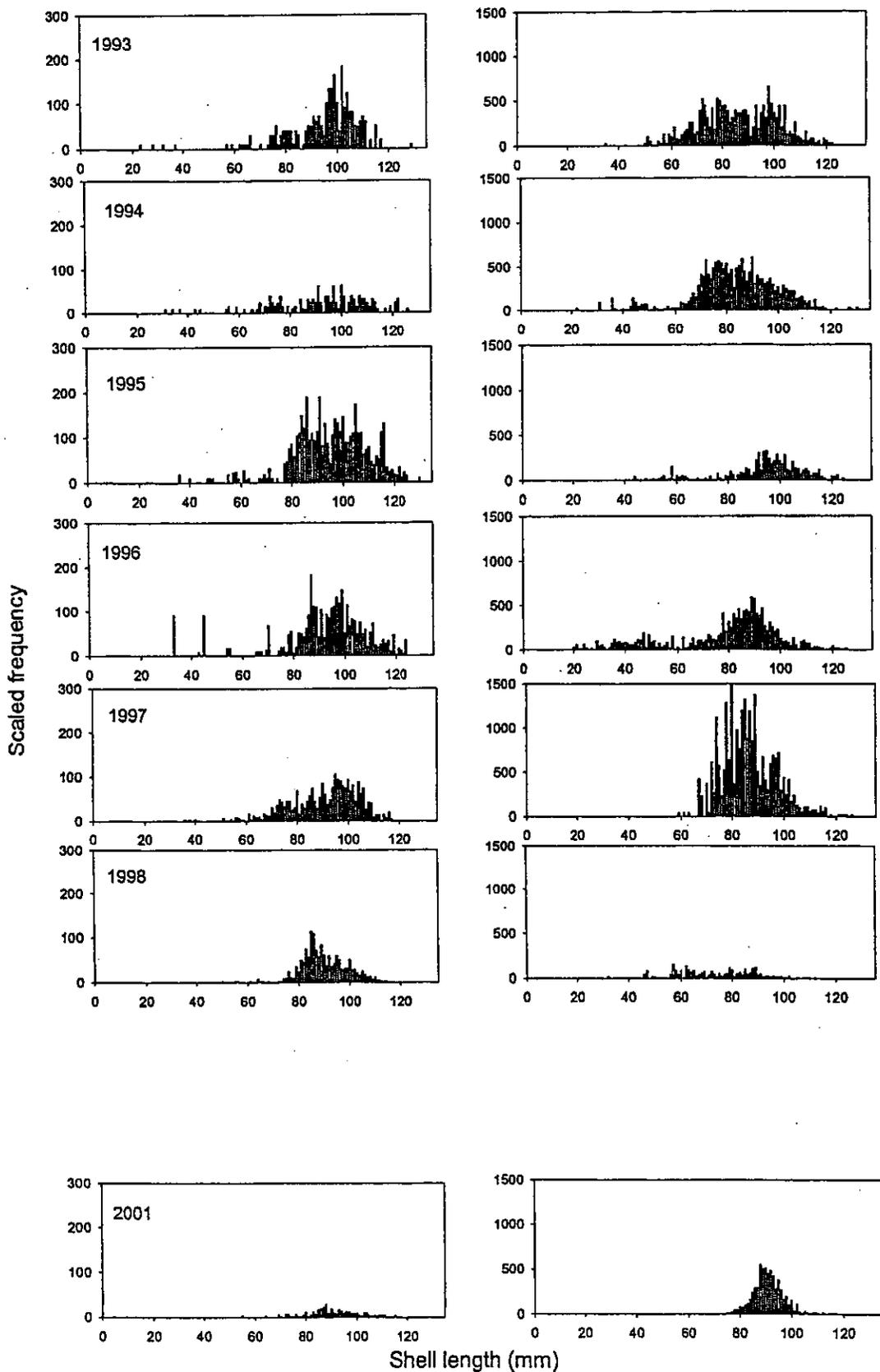


Figure 4: Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Stephenson Island (Whangaroa); right panel, Brëam Bay. The 1997 result for Brëam Bay was based on very few samples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

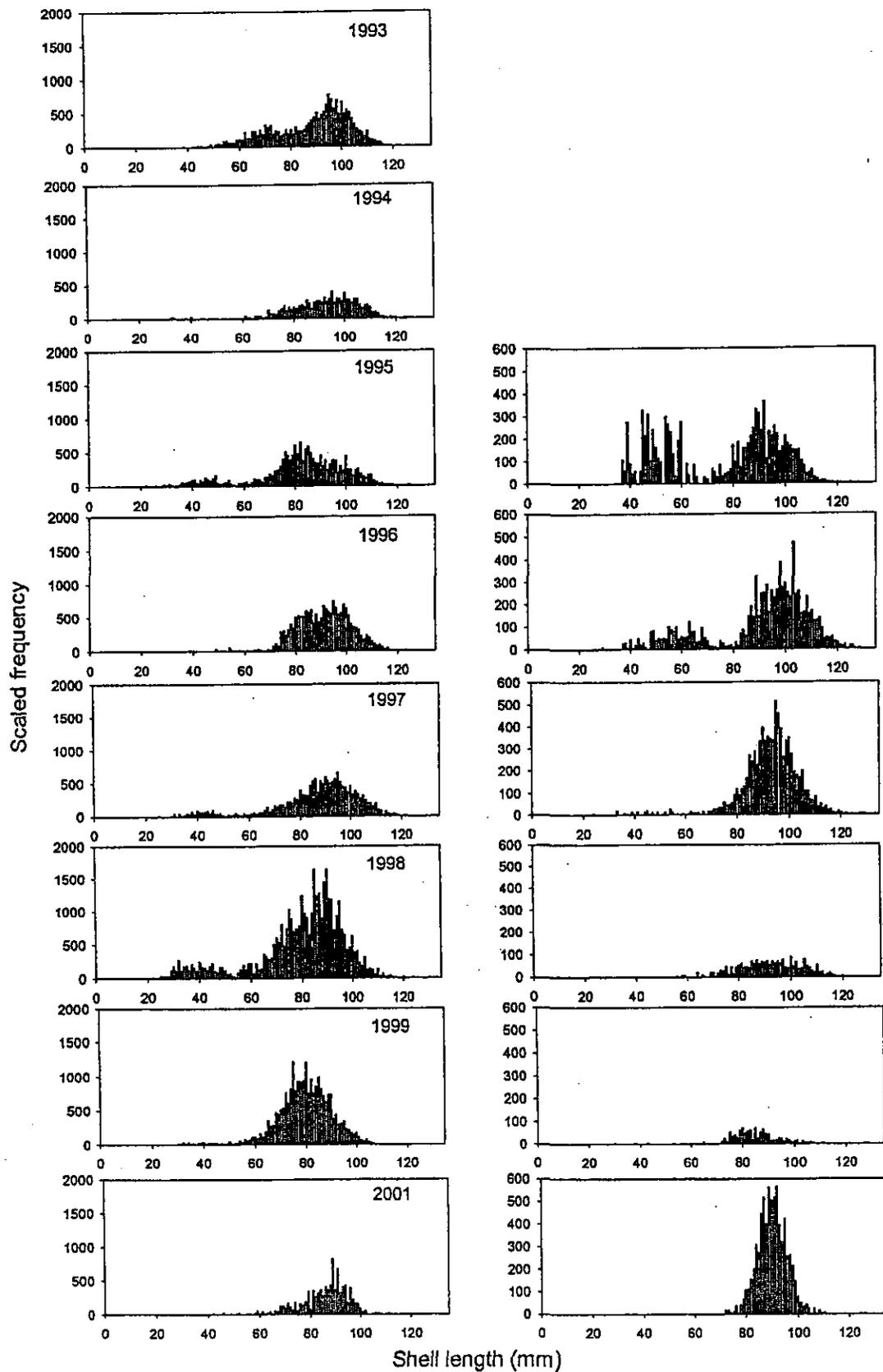


Figure 5: Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected using historical average dredge efficiency by size. Left panel, Mercury Islands; right panel, Little Barrier Island. There were no surveys at Little Barrier Island before 1995.

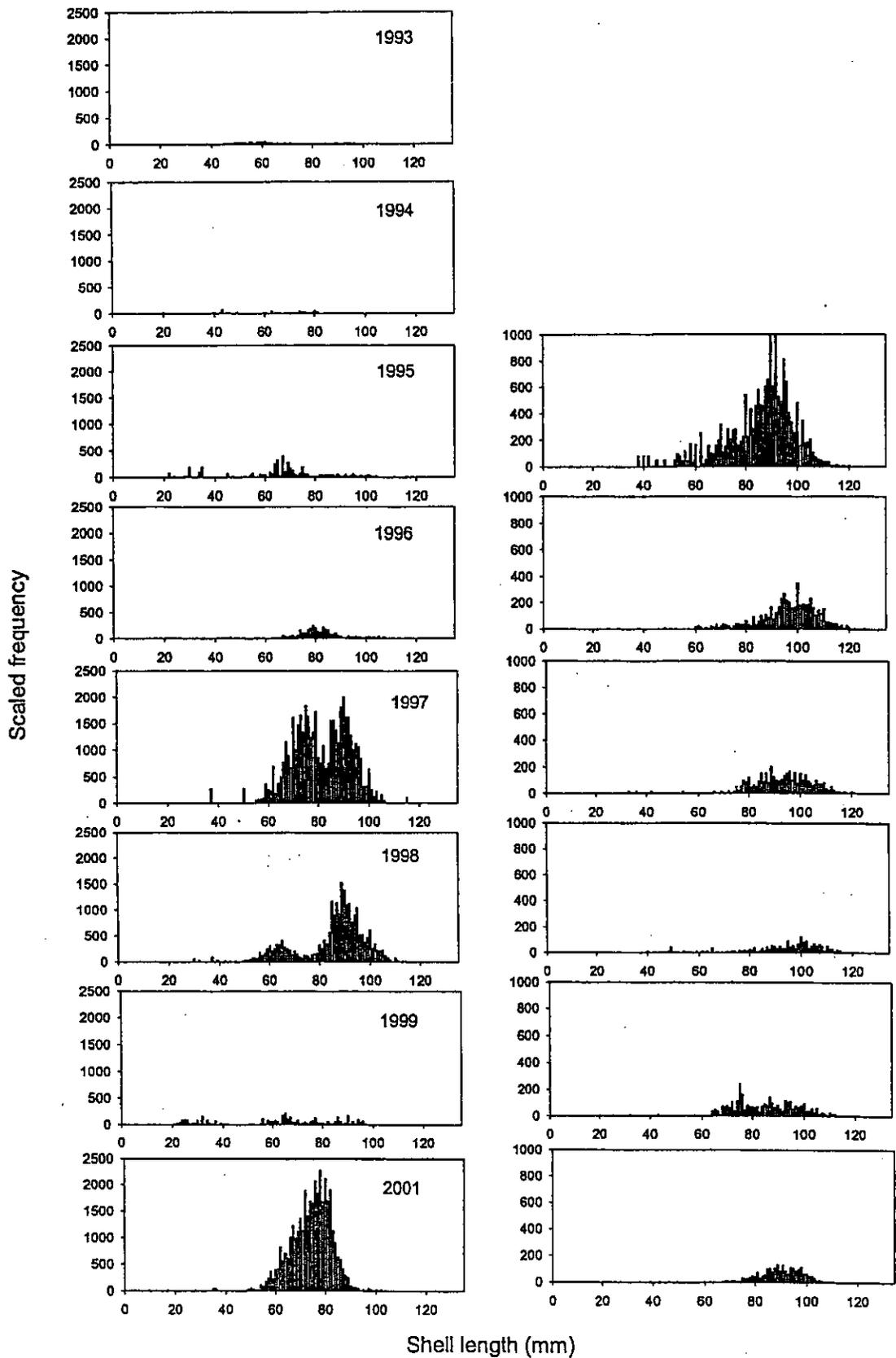


Figure 6: Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected using historical average dredge efficiency by size class. Left panel, Waiheke Island; right panel, Motiti and Papamoa Beach. There were no surveys at Motiti-Papamoa before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

Table 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 more 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 more 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).

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 more 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 more 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

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 (Table 6). 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 m² 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 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.
Northland fishery								
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								
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

3.3 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 found 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 to 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.

3.4 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

$$8.894 \text{ million} * 109.59 * 0.894 = 871 \text{ t (greenweight), or}$$

$$\text{assuming 13.5\% recovery, } 871 * 0.135 = 118 \text{ t (meatweight)}$$

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.

3.5 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

$$8.265 \text{ million} * 76.36 * 0.914 = 577 \text{ t (greenweight), or}$$

$$\text{assuming 13.5\% recovery, } 577 * 0.135 = 78 \text{ t (meatweight)}$$

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.

3.6 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 longer 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

$$2.217 \text{ million} * 96.21 * 0.914 = 195 \text{ t (greenweight), or}$$

$$\text{assuming 13.5\% recovery, } 195 * 0.135 = 26 \text{ t (meatweight)}$$

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.

4. 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 Stephenson 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.

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 7: Number of scallops at the time of survey in constituent areas of the Northland fishery since 1992 (millions 95 mm or more 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

Table 8: Number of scallops at the time of survey in constituent areas of the Coromandel fishery since 1990 (millions 95 mm or more 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

5. CONCLUSIONS

1. Dredge surveys for scallops of 77 and 83 tows, respectively, were carried out in the Northland and Coromandel fisheries in April–May 2001. Strata thought unlikely to support commercial fishing in 2001 and all areas closed to commercial fishing were excluded.
2. Biomass estimates were made by the area swept method, corrected using precautionary interpretations of historical data on dredge efficiency. They are considered to be estimates of absolute biomass.
3. 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%. This is a relatively low estimate (surveys began only in 1992), but is a slight improvement on 1998 survey results.
4. 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%. This is the second lowest estimate since surveys began in 1978, but is a slight improvement on 1999 survey results.
5. Absolute start-of-season biomass over 90 mm shell length in the Coromandel Fishery was estimated to be 577 t greenweight (78 t meatweight) with standard errors of about 27% of the mean.
6. Estimates of biomass from the 2001 surveys (and their precision) are all sensitive to assumptions about dredge efficiency and the minimum fishable density of scallops.

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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	Stephenson 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 Deepes	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