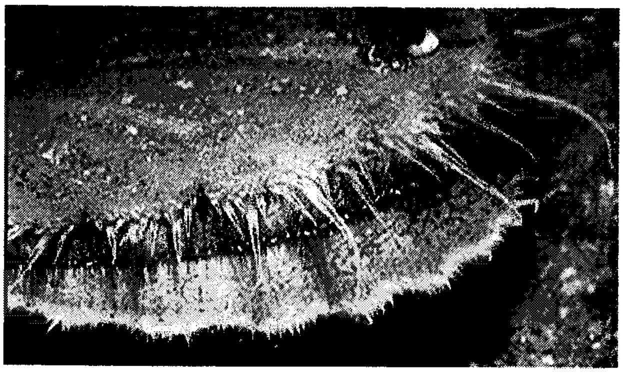
Dredge surveys and sampling of commercial landings in the Northland and Coromandel scallop fisheries, 1998

Martin Cryer
Derrick M. Parkinson



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Contents

Abstract

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Dredge surveys for scallops were carried out in the Northland and Coromandel fisheries in May 1998. Biomass estimates made by the area swept method were corrected for the estimated average efficiency of the dredges used for surveying and are considered to be estimates of absolute biomass. For the Coromandel fishery, absolute start of season biomass over 100 mm shell length was predicted to be 1340 t greenweight (180 t meatweight). Taking into consideration all scallops likely to be over the minimum legal size of 90 mm by the start of the season increased this estimate to 2700 t greenweight (365 t meatweight). Standard errors were estimated by simulation to be about 16% of the mean. Proposed areas for voluntary closure to commercial fishing contain 1% (commercial proposal) or 18–24% (non-commercial proposal) of the estimated biomass. Sampling of landings in the Coromandel fishery suggests that there is considerable heterogeneity in the size selectivity behaviour of fishers; some fishers apparently return to the sea a large proportion of scallops 90–94 mm in length which are above the minimum legal size. Modelling suggests that this behaviour will reduce long term yield. For the Northland fishery, absolute start of season biomass over 100 mm shell length was predicted to be 1550 t greenweight (210 t meatweight). The standard error was estimated by simulation to be about 13% of the mean. Proposed areas for voluntary closure to commercial fishing contain about 5% of the estimated biomass. Growth rates estimated from tag return data were found to be variable among years and to decrease with increasing depth. The K parameter of the von Bertalanffy growth equation was estimated using all available data to be about 1.30–1.40 for both fisheries, but the range was very wide, from 1.70 in shallow water (1992–97) to 0.59 in deep water and in poor years for growth (1984). The L_∞ parameter of the von Bertalanffy growth equation was much less variable than the K parameter, lying in the range 108–114 mm shell length. The implications for variability in growth rate are discussed in relation to the estimation of start of season biomass from survey results.

Introduction

This report describes dredge surveys for scallops (*Pecten novaezelandiae*) carried out under contract to the Ministry of Fisheries (project SCA9701) throughout the major beds of the Northland and Coromandel scallop fisheries during May 1998. Surveys have been conducted in the Coromandel fishery almost annually since 1978, and Northland surveys began in 1992. Survey results have been used to estimate Provisional Yield (PY, after a method by Cryer (1994)) and set catch limits for the Coromandel fishery since 1992 and for the Northland fishery since 1996. Survey designs have been developed and refined over the years using historical survey data, catch-effort information, a review of optimisation procedures, and discussions with managers and fishers.

The principal aim of the survey work was to estimate the absolute abundance of scallops by size class in all major beds of the Coromandel and Northland fisheries. Recruited biomass at the start of the forthcoming season (15 July of each year) is then predicted in greenweight and meatweight using available information on growth, mortality rates, and condition factors.

Starting in October 1997 (half way through the season), and extending through the 1998 season, the Ministry of Fisheries requested information on the length composition of landings in the Coromandel fishery. This information is important because recent modelling has shown that long term yield can be markedly affected by the selection behaviour of fishers (Cryer & Morrison 1997). Although there is no direct estimate of the length composition of scallops caught by fishers for comparison with that of the landed catch, analysis of patterns of variability within the fleet and comparison with the predicted length composition of scallops in the population (generated using the individual based model of Cryer & Morrison (1997)) have been conducted.

Objectives

Biomass surveys were designed to achieve the following objectives.

1. To estimate population abundance and length frequency distributions for the Northland and Coromandel scallop fisheries at the time of surveying.

2. To predict recruited biomass for the Northland and Coromandel scallop fisheries at the start of the 1998 season in mid July.

Sampling of landings in the Coromandel fishery in the 1997 and 1998 seasons was designed to achieve the following objective.

1. To determine the size structure of the commercial scallop landings during the 1997 and 1998 seasons, incorporating at least 20 landings per month from the ports of Whitianga and Whangamata. A minimum of 200 scallops will be measured from each landing.

Methods

Survey timing

Both fisheries were surveyed in May 1998. It was originally planned to survey Northland earlier in the year but, after consultation with fishers and local staff of the Ministry of Fisheries, this work was delayed to early May, shortly before the fieldwork for the Coromandel fishery. 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, settled weather, and warm water temperatures (for divers), but the long time lag between survey completion and season opening render biomass estimates sensitive to the accuracy of assumed values for growth and mortality. In addition, scallops are susceptible to periodic catastrophic declines in abundance and a longer lag time between survey and season clearly increases the probability of such an occurrence. Surveys undertaken later in the year can be hampered by short working days and less favourable conditions, and the danger of surveys being seriously delayed by inclement weather increases. However, the impact on biomass estimates of poor assumptions about growth and mortality is smaller, and the chance of catastrophic declines in abundance following the survey is reduced. For 1998 surveys, all diving and dredging work was completed by late May.

Survey design

All sampling for the 1998 surveys was, at the request of the Ministry of Fisheries, undertaken by dredge, and diving activity was limited to that necessary to estimate dredge efficiency.

For the Coromandel fishery, sampling was undertaken at Waiheke Island (5 previous strata amalgamated to 1), Little Barrier Island (2 strata), Colville (3 strata), Whitianga (9 strata), Slipper Island (2 strata), Katikati (Waihi) (2 strata), and Motiti Island to Papamoa (4 strata). The total sampled area was 341 km^2 in 23 strata (compared with 280 km^2 in 1996 and 253 km^2 in 1997, Figure 1, Appendix 1).

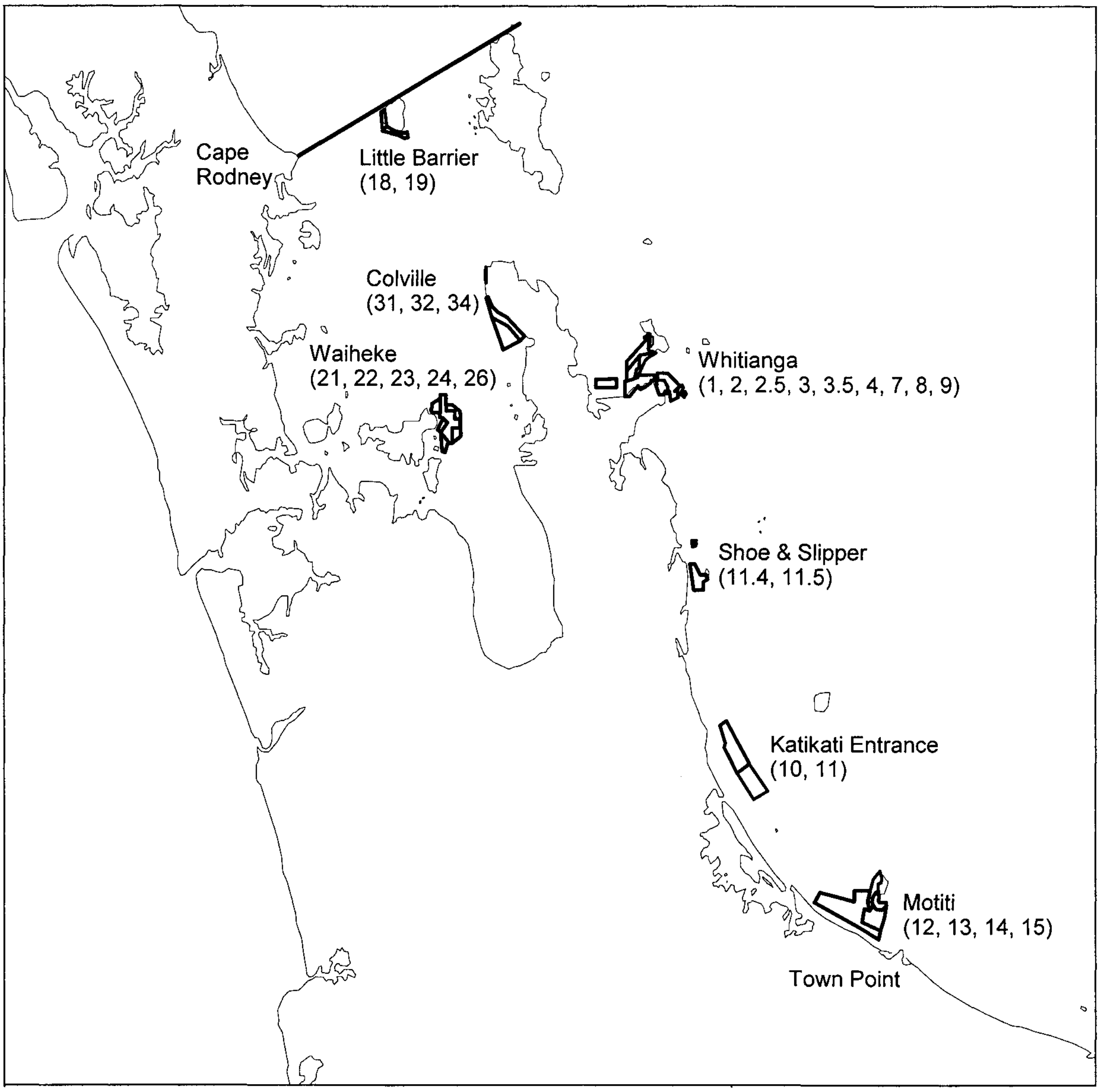

***Figure 1*: Location of strata for the survey of the Coromandel scallop fishery 1998. Code numbers for strata are given in parentheses (*see* Appendix 1 for details and stratum areas).**

For Northland, sampling was undertaken in Spirits Bay (2 strata), Tom Bowling Bay, Great Exhibition Bay, Rangaunu Bay (2 strata), Doubtless Bay, Stephensons Island (Whangaroa), Flat Island, the Cavalli Passage, Matauri Bay, Takou Bay, Bream Bay (2 strata), and the coast between Mangawhai and Pakiri (3 strata). The total sampled area was 714 km^2 in 17 strata (compared with 553 km^2 in 1996 and 663 km^2 in 1997, Figure 2, Appendix 2).

Sampling in both fisheries was two phase stratified random with about 10% of shots being allocated to a brief second phase in each area.

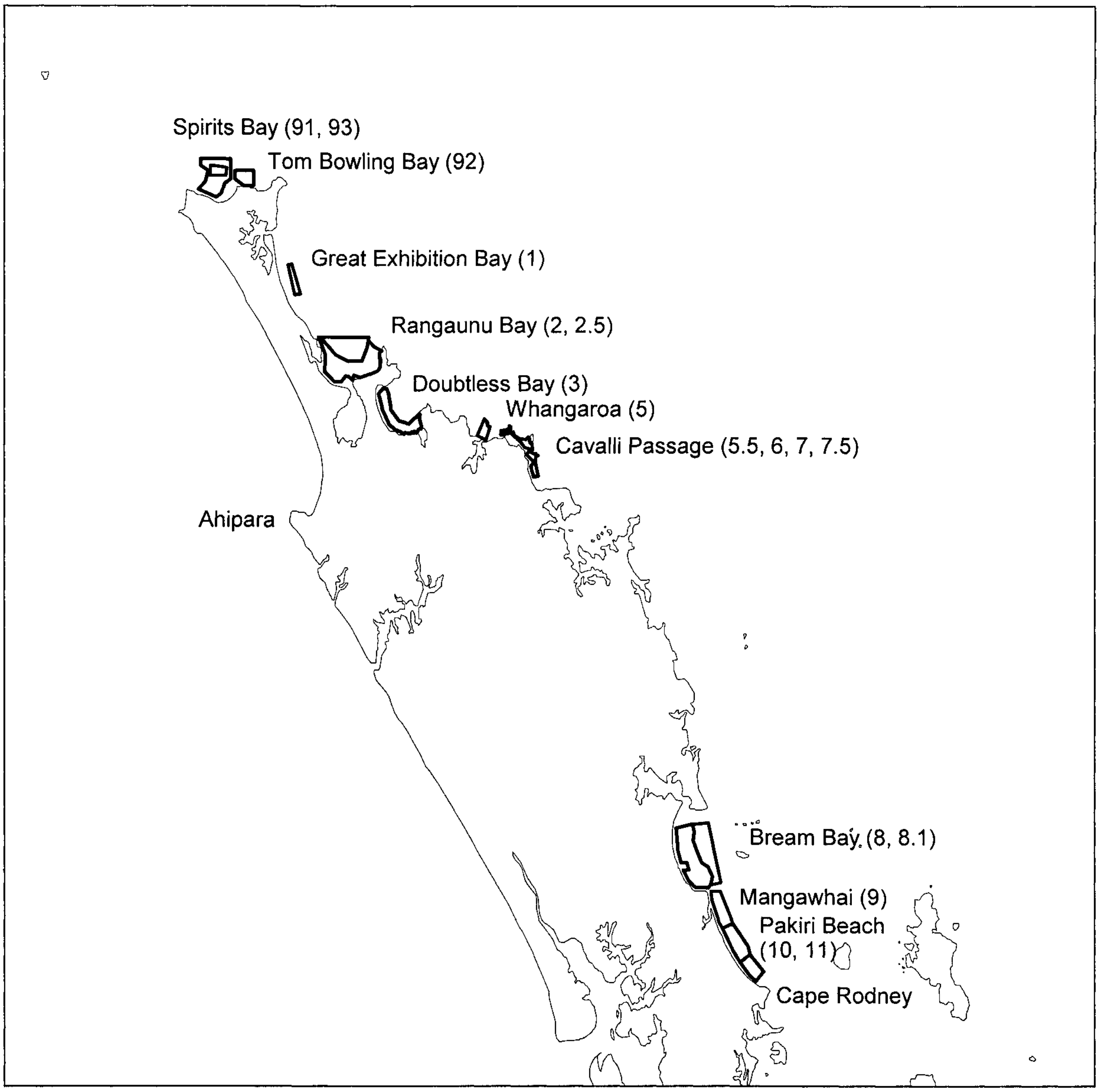

***Figure 2*: Location of strata for the survey of the Northland scallop fishery 1998. Code numbers for strata are given in parentheses (*see* Appendix 2 for details and stratum areas).**

Survey optimisation and allocation of stations to strata

The performance of the optimisation procedure used in previous surveys (based on the density of pre-recruits in the year before the survey to be optimised) was examined by comparing the predicted and actual performance of the 1996 and 1997 surveys. The performance of several alternative methods of optimisation were compared with that of the current design procedure (Appendix 3). The results of this analysis suggest that the high temporal and spatial variability of scallop populations mean that no simple optimisation procedure will consistently outperform the rest. The most consistent optimisation procedure was found to be one based on the "average" outcome of four simple procedures based on stratum size, the density and variability of undersized scallops in the previous year, and the density and variability of legal sized scallops since 1993 (Equation (1)).

$$n_i = N \,.\, \Sigma_{i,k} \{A_i \, V_{i,k} / \Sigma_i A_i \, V_{i,k}\}/n_k \qquad (1)$$

where N is the total number of sites in the sampling phase, n_i is the number of samples allocated to stratum i of area A_i and variability V_i using allocation method k (Sukhatme & Sukhatme 1970). Four predictors of likely variability, V_i, were used ($n_k = 4$), being the mean density of scallops less than 95 mm shell length (85 mm for the Coromandel fishery) within each stratum in the previous year's survey, the standard deviation of this mean, the mean historical density of scallops greater than 95 mm shell length within each stratum, and the standard deviation of this mean. Because using very small minimum allocations of shots to strata is risky (Appendix 3), a minimum allocation of four shots per stratum was used. Where possible, allocations of shots to strata were made such that daylight hours could be fully utilised for sampling and steaming between strata could be undertaken during the hours of darkness. Within these constraints, shots were allocated to strata according to Equation (1).

Shot position selection

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 outputs the latitude and longitude of each random station. A separate and completely independent list of second phase stations (which also served as a list of replacement stations) for each stratum was also generated.

Second phase stations were allocated in the field according to Equation (1b) wherein N became the total number of sites to be sampled in both phases combined for the group of strata subject to two phase sampling. Second phase allocations were made according to the number of sites in each stratum already completed (or projected to be completed), the amount of time remaining, and the variability of counts already made.

$$n_i = N \,.\, A_i \, V_{i,} / \Sigma_i A_i \, V_{i,} \qquad (1b)$$

where N is the total number of sites likely to be completed in the two sampling phases combined, n_i is the total number of samples allocated to stratum i of area A_i and standard deviation V_i (Sukhatme & Sukhatme 1970).

Vessels and gear: dredge sampling

Dredging was undertaken from the chartered commercial dredge vessels *Marewa* (Northland fishery) and *Kataraina* (Coromandel fishery). The same vessel and skipper has been used since 1995 for the Coromandel fishery, but this is the first time *Marewa* and her skipper have been used in the Northland assessment (being the fourth vessel used in six surveys).

Vessels were navigated to each site in turn using a (non-differential) GPS plotter. At the appropriate position the dredge was lowered to the bottom and warp was paid out until the dredge was considered by the skipper to have "bitten" into the bottom. The dredge was towed in a direction and at a speed selected by the skipper to optimise the performance of his gear until a distance of 0.50 nautical mile over the ground (as determined by non-differential GPS) had been covered. The dredge occasionally lost contact with the bottom or "flew" in response to a range of factors (hard or uneven substrate, increase in depth, dredge full of detritus or scallops, etc.) and, on these occasions, the tow was terminated. The actual distance travelled along the ground was estimated for all shots using GPS.

At the completion of each tow, the dredge was retrieved and emptied onto the sorting tray on the boat. All live scallops were removed, counted, and their maximum length measured to the nearest millimetre down.

Occasionally, very large catches were randomly subsampled for length. All unmeasured scallops were counted.

Estimating dredge efficiency

Dredges cannot be considered to be 100% effective at retaining scallops found in the sampled area and several previous studies have shown that such efficiency can vary widely (e.g., Allan 1984, Bull 1988, Cryer & Parkinson 1993a, 1993b, 1994a, 1994b, 1997, Cryer & Morrison 1997). All strata in 1998 surveys were sampled by dredge and therefore required correction for sampling efficiencies of less than 100%. Separate determinations of dredge efficiency by direct comparison with diver counts have been carried out for the two fishery areas, and for muddy and sandy substrates.

Divers were deployed from RV *Artedi*, a purpose-built 6.8 m alloy pontoon boat. The vessel was navigated to each dive site in turn by use of a combined non-differential GPS marine plotter. A heavy anchor was set and this acted as a descent line for the divers and marked the centre of the search pattern on the seabed. Two divers descended to the seabed and attached to the shot a sweep rope of 8 m total length marked 3 m from its free end. The search area for each site was defined by the area traversed by the sweep line, and three alternative search areas were therefore available: a circle of radius 8 m (201.06 m^2); a circle of radius 5 m (78.54 m^2); or a "doughnut" comprising the 8 m circle less the 5 m circle (122.52 m^2). This adaptive approach was developed to minimise dive time while avoiding the large number of zero counts in some previous surveys.

On approaching the sea bed, the lead diver made a visual assessment of the density of scallops. If the diver considered that a 5 m search was likely to lead to more than about 20 near legal sized scallops, then the smaller search circle was selected. Alternatively, the larger circle was used. The divers progressed to the end of the sweep line and positioned themselves about 1 m apart. The start position for the search was marked using a small float attached to a weight. The divers swam a complete circuit of the search pattern while maintaining the sweep line taut: all scallops passing under the sweep line were collected by the divers and kept in spring-loaded catch bags. If the larger circuit was being searched, then only scallops falling outside the 3 m mark were collected on the first circuit. At the completion of the first circuit, the divers conferred. If the 5 m circle was being searched or fewer than 20 near legal sized scallops had been collected from the outer ring of the 8 m circle, then the divers each moved about 1 m towards the shot, and continued the search. The search was ended on completion of the chosen circle, or if more than about 20 near legal sized scallops had been collected from the outer ring of the 8 m circle, or if the divers approached within 3 minutes of their maximum no-decompression limits.

Under highly turbid or muddy conditions, circular searches are highly impractical because sediment stirred up by the divers quickly obscures their vision. For this reason, 2 m wide linear transects directed from the anchor and into the prevailing current were searched by divers when reduced visibility is likely to hamper the efficiency of circular searches. Standard circular searches are the method of choice, however, because most of the area is double searched, leading to higher efficiency.

Whatever the search pattern, on completion of the search, the divers removed the sweep line from the anchor and returned to the boat with the bags of scallops. All scallops from each station were measured across their maximum length to the next whole millimetre down. Measurements were recorded together with the date, station number, search area, and depth of water. The efficiency of dive searches was assumed to be 100% with zero variance.

Divers worked with surface support comprising standby diver, standby snorkeller, and two other personnel. Standard compressed air was used in conjunction with PADI. "12 hour" tables, substituting surface-to-surface time for the standard surface-to-start-of-ascent time. Diving and other duties were rotated to ensure the maximum surface interval between dives and minimum individual nitrogen exposure. These arrangements slightly exceed the requirements of the diving code of practice registered with the Department of Labour.

For both Northland and Coromandel fisheries, dredge efficiency has been found to vary considerably among the studies conducted. Dredge efficiency and its inverse (the biomass multiplier) were therefore estimated for each study, and the data combined to estimate mean efficiency for the two broad substrate types studied. For estimation of start of season recruited biomass and its variance, separate pooled estimates of dredge efficiency on sand and on mud were generated by combining all historical estimates (including those for 1998) of efficiency on the two sediment types for scallops over 90 mm in length. The average biomass multiplier and its *c.v.* were used directly in the estimation of scallop abundance and biomass. The use of a composite dredge efficiency estimate entails the implicit assumption that random and site effects are more important than any year effect.

For the Coromandel fishery, all estimates of efficiency and selectivity have been made using the two similar vessels (in terms of tonnage, horsepower, reduction gear, and propellers) *L'Aries* and *Kataraina*, so pooling of data seems reasonable. For Northland, however, this is the first survey carried out using the vessel *Marewa*, and the historical data have been derived from three other vessels. The use of pooled dredge efficiency estimates in these circumstances is more questionable and implies an assumption that the average efficiency of *Marewa* during the survey was similar to that of the other vessels examined in historical dredge efficiency trials. However, if historical data are not used for Northland, then only 1998 estimates will be available for correction of dredge catch rates.

For the Northland fishery, the Stephensons Island (Whangaroa) and Matauri Bay strata were selected as dredge efficiency areas based on preliminary results from the dredge survey suggesting that the density of scallops in these strata was relatively high. Diving, using circular searches, was undertaken at each of the 18 computer-generated random dredge sites in these strata. The depth of water at these sites varied from 10 to 32 m, and the substrate varied from flat sand to shell gravel and *Tawera* beds.

In 1996, dredging was conducted in the Northland trial areas up to 13 weeks after the completion of diving and this was found not to provide a good basis for the estimation of dredge efficiency (presumably because of imperfect correction for growth and mortality, and because scallops may have been moved by strong winds and tides). In 1997 and 1998, therefore, dive and dredge sampling of experimental areas were conducted within 2–3 weeks of one another. In 1998, some of the sampling was undertaken on the same day.

For the Coromandel fishery, the Waiheke Island stratum was selected as the dredge efficiency area because the density of scallops was relatively high and more information on muddy substrates was required. Four dredge sites where over 200 scallops of more than 95 mm shell length had been caught during the survey and where the likely depth of water during diving was less than 30 m were selected. Diving (using linear transects) was undertaken at four sites chosen haphazardly (but less than 0.05 n. mile as judged by non-differential GPS) from each of the selected dredge sites (16 dive sites in all).

For both fisheries, dredge stations used for the assessment were also used to estimate dredge efficiency, so it can reasonably be assumed that dredging was conducted in a manner identical to that employed during routine sampling. Dredge efficiency was calculated as the ratio between the actual and expected catch of scallops in 10 mm size classes, assuming the sampled area to be the length of the towing distance multiplied by the (inside) width of the dredge. The density of scallops over which the dredge was working was estimated as the calculated mean density for given size classes of scallops for diver counts carried out within the given area. No compensation for removals by dredge or by divers was made as almost all scallops caught were tagged and returned to the water within the experimental strata. No compensations for expected growth or mortality were made as the time between sampling events was always very short (less than 2 weeks).

Length frequency estimation and scaling

Almost all scallops from the Northland fishery were measured, whereas the larger samples taken in the Coromandel fishery were sometimes subsampled. 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 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).

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. Available information (Cryer & Parkinson 1997, Cryer & Morrison 1997) suggests 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. Recruited start of season biomass was therefore estimated using critical sizes at the time of the survey of 95 mm (for a size of 100 mm at the start of the season) or 85 mm (for a size of 90 mm at the start of the season).

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 was calculated by multiplying the areal 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 density in each group of strata were derived using the formula for strata of unequal sizes (Equation (2)) given by Snedecor & Cochran (1989):

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

where $s^2_{(y)}$ is the variance of the overall mean density of scallops in the surveyed area, W_i is the relative size of stratum i, and S_i^2 and n_i are the sample variance and the number of samples respectively from that stratum. The finite correction term, $(1 - \phi)$, was set to unity because the sampling fraction was always less than 0.01. The standard error of the overall mean (SEM) 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. It should be borne in mind that these two estimates of population abundance and their variances are not corrected for sampling efficiency.

Corrections for dredge efficiency on sand and mud were made by multiplying the estimated abundance of scallops over the critical size by the mean of the reciprocals of all historical estimates of dredge efficiency for scallops of 90 mm or greater. Dredges were assumed to be similarly efficient for all scallops larger than 85 mm shell length and the same dredge efficiency corrections were made for the two critical sizes of 95 and 85 mm. The overall abundance of scallops over the critical size, N_{total}, in the entire survey area (or any subset of strata), was estimated as the sum of the two estimates by sampling method from Equation (3):

$$N_{total} = \sum N_j . E_j \tag{3}$$

where N_j is the estimated abundance within strata sampled using method j (dredge on sand, dredge on mud), and E_j is the mean of the reciprocals of all reliable historical estimates of efficiency using method j. The variance for this estimate was estimated by simulation using Equation (4):

$$\hat{N}_{total} = \sum (N_j + \varepsilon_{n,j}).(E_j + \varepsilon_{e,j}) \tag{4}$$

where $\varepsilon_{x,j}$ 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 technique for estimating scallop abundance and its variance is identical to that used in 1997 (Cryer & Parkinson 1997). Before that assessment, dredge efficiency was usually incorporated as a selectivity function of size which was been 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 are overly optimistic.

Start of season recruited biomass for strata sampled using a given method, j, was estimated as the product of N_j (for scallops 95 mm or more in length) an estimate of average weight, $\overline{W}_j$, and the expected survival of scallops between the mean survey date and the start of the coming season in mid July (Equation (5)):

$$B_{recruited} = \sum N_j . E_j . \overline{W}_j . e^{-(t.M)} \tag{5}$$

where M is an assumed instantaneous rate of natural mortality ($M = 0.40$ y^{-1}) 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 (6)):

$$W = 0.00042\, L^{2.662} \tag{6}$$

where W is the greenweight (g) and L the maximum shell length (mm, n = 861). The $\overline{W}_j$ for Equation (5) were derived incorporating all scallops of 100 mm or greater shell length within strata sampled using method j at the time of the survey (Equation (7)):

$$\overline{W}_j = \frac{\sum W_{l,j} . N_{l,j}}{\sum N_{l,j}} \tag{7}$$

where $N_{l,j}$ and $W_{l,j}$ are respectively the number and predicted weight 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 growth and mortality would have opposite and approximately equal impacts on population length frequency distribution).

The variance for the estimated start of season recruited biomass was estimated by simulation using Equation (9):

$$\hat{B}_{recruited} = \sum \ (N_j + \varepsilon_{n,j}).(E_j + \varepsilon_{e,j}).\overline{W}_j.e^{-(t.M)} \tag{8}$$

where $\varepsilon_{x,j}$ 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.

The method of deriving confidence limits for an estimate of start of season recruited biomass using the parametric bootstrap described in Equation (9) is different from the method previously employed for this fishery. Between 1993 and 1996, a non-parametric bootstrap technique was applied whereby the raw data for each stratum and the raw data for each of the several historical estimates of dredge efficiency on that substrate type were re-sampled for each stratum in each bootstrap. The bootstrap abundance of scallops in a given stratum was estimated as the mean of the bootstrap observed density estimates multiplied by the area of the stratum, and divided by the bootstrap estimate of dredge efficiency for that stratum. A bootstrap estimate of total abundance is simply the sum of all the stratum estimates for that bootstrap (Equation (9)).

$$\hat{N}_{total} = \sum_i \frac{A_i * \sum \frac{\hat{d}_i}{n_i}}{\frac{\sum \hat{d}_{d,k} / n_{d,k}}{\sum \hat{d}_{s,k} / n_{s,k}}} \tag{9}$$

where $\hat{d}_i$ are randomly re-sampled (uncorrected) density estimates within stratum i of area A_i, and $\hat{d}_{d,k}$ and $\hat{d}_{s,k}$ are randomly re-sampled density estimates by dredge and dive respectively within experiment k. The dredge efficiency experiments are chosen at random, constrained such that the sediment type is similar for sampling stratum and efficiency experiment.

Prediction of seasonal average recovery fraction

Catch limits or TACCs for northern scallop fisheries are 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. Consequently, the recovery of meatweight from greenweight varies according to where and at what time of year the fleet is fishing, and the prediction of an average recovery of saleable meats from a given greenweight of scallops over a season becomes very difficult. Fleet average recovery rates can be as high as 20% in some weeks, but can also slip below 10% just after a spawning event (usually in October or November).

The approach to this problem taken here is to amalgamate all historical data where length, greenweight, and meatweight are 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. In addition, the relationship between estimated greenweight and actual meatweight from CELR forms has been examined, although the estimated greenweight and the data to enable greenweight to be estimated from the number and size of bins landed are frequently not well reported.

Tagging for growth rates and migration

All scallops from diver surveys and samples of scallops in good condition from dredge surveys were tagged using uniquely numbered polythene tags attached with cyanoacrylate "superglue" to the flat shell close to the hinge. The date, location, and depth were recorded at capture and release for all tagged scallops.

Francis's (1988) method, GROTAG, is the preferred method of analysing tag return data when the time at liberty is not constant. A maximum likelihood approach is used to estimate the average annual increment for two arbitrary initial sizes. These sizes are selected by the user such that they cover the broad spread of the available data, without extending beyond the data. Francis cautions that length-based tag return data are not directly comparable with age-based growth functions such as that of von Bertalanffy (because there is no explicit age information in the tag-return data). With that caveat in mind, the two expected annual increments at arbitrary size can be used to estimate likely values of the length based von Bertalanffy parameters K and L_∞ as follows:

$$K = -\log_e\left(1 + \frac{\Delta L_1 - \Delta L_2}{L_1 - L_2}\right) \tag{10}$$

$$L_\infty = \frac{L_2.\Delta L_1 - L_1.\Delta L_2}{\Delta L_1 - \Delta L_2} \tag{11}$$

where L_1 and L_2 are the two arbitrary sizes, and ΔL_1 and ΔL_2 are the respective estimated annual increments at those sizes.

Sampling of Coromandel landings in 1997 and 1998

The Ministry of Fisheries specified a target sampling of 20 landings per month, with at least 200 scallops to be measured from each landing.

We selected two dates at random from within each month, constrained so that scallops would be available for measurement in the sheds on those days (fishing days are Sunday to Thursday, meaning that scallops are available to be measured Monday to Friday). On each of the random days (or as close as possible to the random days when there were disruptions to fishing or processing), we planned to sample six landings at the shed in Whitianga and six at the shed in Whangamata. If the targets were perfectly met, this would have led to 24 landings being sampled each month. In the event, it was not possible to sample at the two sheds on the same day (due to the likelihood of interfering with processing schedules in the sheds) and it was rarely possible to sample six landings in a day (because of small numbers of landings, for instance). Because of these problems, which were especially severe during the 1998 season when fishing was very poor, sampling was not strictly random, and we sometimes sampled landings as and when they were available.

A bin of scallops in the Coromandel fishery typically contains about 350 individuals so, to avoid the complications inherent in taking a random sample from within a bin, we measured all scallops from a bin selected at random from each landing. All scallops within the randomly selected bin were measured to the next whole millimetre below the actual length, using methods as close as possible to those used in surveys.

Length frequency distributions were grouped by month, weighted by the number of bins in each landing. Thus, if the selection of landings for measurement is assumed to be random and the size of bins is constant, then the monthly weighted length frequency distribution is an unbiased estimate of the length frequency distribution of fleet landings from the Coromandel fishery. To assess the level of heterogeneity of behaviour within the fishery, smaller groupings by month (again weighted by the number of bins in each landing) were made by segregating the fleet into three groups according to the average size of their smallest scallops. The lower 5 percentile size was calculated for each landing, and the average of these calculated for each vessel in 1997 and 1998. Lower 5 percentiles were selected as a measure rather than the smallest scallop in each landing because it seems to be more consistent and less prone to outliers (such as the occasional very small scallop inadvertently included in a bin). After excluding vessels with less than three landings in 1997 (five landings in 1998), the three vessels having the highest mean 5 percentile size in each year were grouped together as those most likely to demonstrate "high grading" of catches. Similarly, the three vessels having the lowest mean 5 percentile size in each year were grouped together as those least likely to demonstrate high grading. The remaining four vessels in each year were placed in an intermediate group. The groupings were similar, but not identical, in the two years.

As there was no mid-season survey or catch-at-sea information to provide a direct estimate of the length frequency of catches (as opposed to landings), an expected length frequency distribution of catches in each month was developed using the stochastic individual based model (sIBM) developed by Cryer & Morrison (1997). This model considers each animal as an individual and has temporal steps of one month. Each animal has calculable probabilities each month that it will die of natural causes, or be encountered by a dredge. If it does not die and is not encountered by a dredge, then the animal will grow at the "normal" rate. If it is encountered by a dredge, then it has calculable probabilities of capture by the dredge, and selection by the fisher. Different "incidental" mortality rates and subsequent growth rates apply to scallops not retained by the dredge and retained by the dredge but returned to the sea. Scallops retained by the dredge and the fisher are the catch and reflect fishing mortality *sensu stricto*.

Initial length frequency distributions for the two years were generated using the survey results from 1997 and 1998, corrected for average dredge efficiency by size class. Strata at Waiheke Island were excluded from these analyses because there was very little fishing in this area in either year. The lack of fishing at Waiheke means that these strata should not be included in any population used to generated expected length frequency distributions, especially since the length frequency distribution of this bed is often markedly different from that of other beds. Thus, the initial length frequency distributions were estimates of the population length frequency distribution across all beds, excluding Waiheke Island.

The initial length frequency distribution was used to generate initial lengths for 10 000 individuals in April (1997) or May (1998) for the sIBM. These initial lengths were then projected forward using the following assumptions.

1. Model fishing effort approximately equivalent to an annualised rate of fishing mortality, F, of 0.6 for scallops of 90 mm or greater length, with a season running from July to December (relative fishing effort being 0.10, 0.20, 0.20, 0.20, 0.20, 0.10 in the six calendar months of the season).

2. Annualised natural mortality, M, of 0.40, spread evenly across the whole year.

3. A dredge efficiency curve described by a logistic curve with a maximum efficiency of 43%:

$$S = \frac{0.434}{1 + e^{(4.32 - 0.062.L)}} \qquad (12)$$

   where S is the probability of retention for a scallop of shell length L (mm), 0.434 is the maximum probability of retention, and 4.32 and 0.062 are fitted parameters describing the location and steepness of the curve. The point of inflection is at a shell length of about 70 mm.

4. A probability of death following an encounter with a dredge described by two logistic curves:

$$M_r = \frac{1}{1+e^{(3.73-0.031.L)}} \qquad (13)$$

$$M_m = \frac{1}{1+e^{(5.71-0.050.L)}} \qquad (14)$$

where M_r and M_m are, respectively, the probabilities of death following an encounter in which the dredge does or does not retain a scallop which subsequently ends up in the sea (those retained by fishers all die). The point of inflection of both curves is greater than 100 mm, a size above which all scallops are highly likely to be retained. Effectively, therefore, both curves are monotonically increasing over the length range considered here.

5. Monthly growth increments are described by three simple linear regressions of increment on initial length:

$$I_n = 9.225 - 0.0891.L + \varepsilon \qquad (15)$$

$$I_m = 9.186 - 0.0942.L + \varepsilon \qquad (16)$$

$$I_r = 8.874 - 0.0942.L + \varepsilon \qquad (17)$$

where I_n, I_m, and I_r are, respectively, the monthly increment in shell length, L, for scallops having had no dredge encounters in the previous month, an encounter during which they were not retained, or an encounter during which they were retained by a dredge and subsequently returned to the sea. In all three regressions, there is a stochastic error term, ε, with values being drawn at random from a normal distribution of mean 0 and standard deviation 1.2 mm.

For each month between July and December in 1997 and 1998, the lengths of all surviving scallops in the model were used to construct estimated population length frequency distributions. Similarly, the lengths of all scallops considered to be retained by dredges in those months were used to construct estimated length frequency distributions of dredge catches. Expected length frequency distributions of landings were constructed by truncating the length frequency distributions of dredge catches at the minimum legal size, MLS, of 90 mm.

Observed (landed catch) and "expected" (modelled) length frequency distributions were compared using grouped landing data. No monthly observed length frequency distribution presented here contains landings from less than three vessels. For each month where landings data were available, the ratio between the observed and expected proportion at length was calculated and compared with the expected pattern of knife edge recruitment at 90 mm.

Results

General considerations

Impact of the change of analytical method in 1997

The consequences of improving the analytical technique in 1997 were examined by conducting parallel analyses using both techniques for the 1997 Coromandel assessment. The parametric bootstrap technique applied here and in 1997 led to an estimated *c.v.* for the start of season recruited biomass of 19.3% with a symmetrical probability distribution. The non-parametric bootstrap used for assessments between 1993 and 1996 was applied to these same data and generated a nominal *c.v.* of 24.6% with a probability distribution which was markedly skewed right (i.e., the high biomass tail was longer than the low biomass tail, Figure 3). As the lower tail of the probability distribution is used in the calculation of Provisional Yield (Cryer 1994), the steepness of this tail is more important than the overall *c.v.* when using the non-parametric bootstrap to estimate the lower confidence bound and yield. Using this approach (as in previous assessments), the *c.v.* for the start of season recruited biomass for the Coromandel fishery was estimated to be 18.6%. The difference between this and the *c.v.* derived using the parametric approach (19.3%) led to a difference of only about 2% in yield estimates and this was considered trivial.

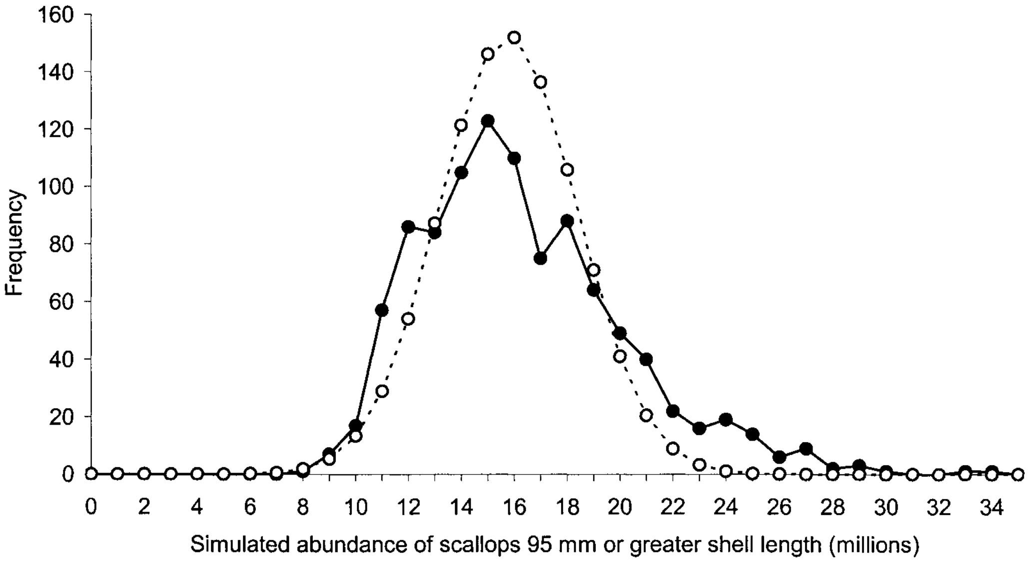

***Figure 3*: Comparison of the frequency distributions for the simulated abundance of scallops generated by non-parametric bootstrap (1993–96 method) and parametric bootstrap (1997 and 1998 method), using data for the 1997 Coromandel assessment scaled to the same mean. Solid lines and circles, non-parametric; dashed lines with open circles, parametric analysis.**

Bias associated with estimating biomass using length frequency distributions and a length weight regression

Simulations suggest that any bias associated with the use of length frequency distributions and a length weight regression to estimate biomass is small (Figure 4). The estimated bias for modest samples of 500 animals over 100 mm in length (chosen at random with replacement from 2504 available) was +0.2% for greenweight and -1.5% for meatweight. Where scallops over 90 mm were selected, the bias was +0.1% for greenweight and +0.8% for meatweight. In none of these four tests was the average bias (from 1000 simulations) significantly different from zero. It is concluded from this analysis that the estimation of biomass from length weight distributions and an appropriate length weight regression for scallops is largely unbiased.

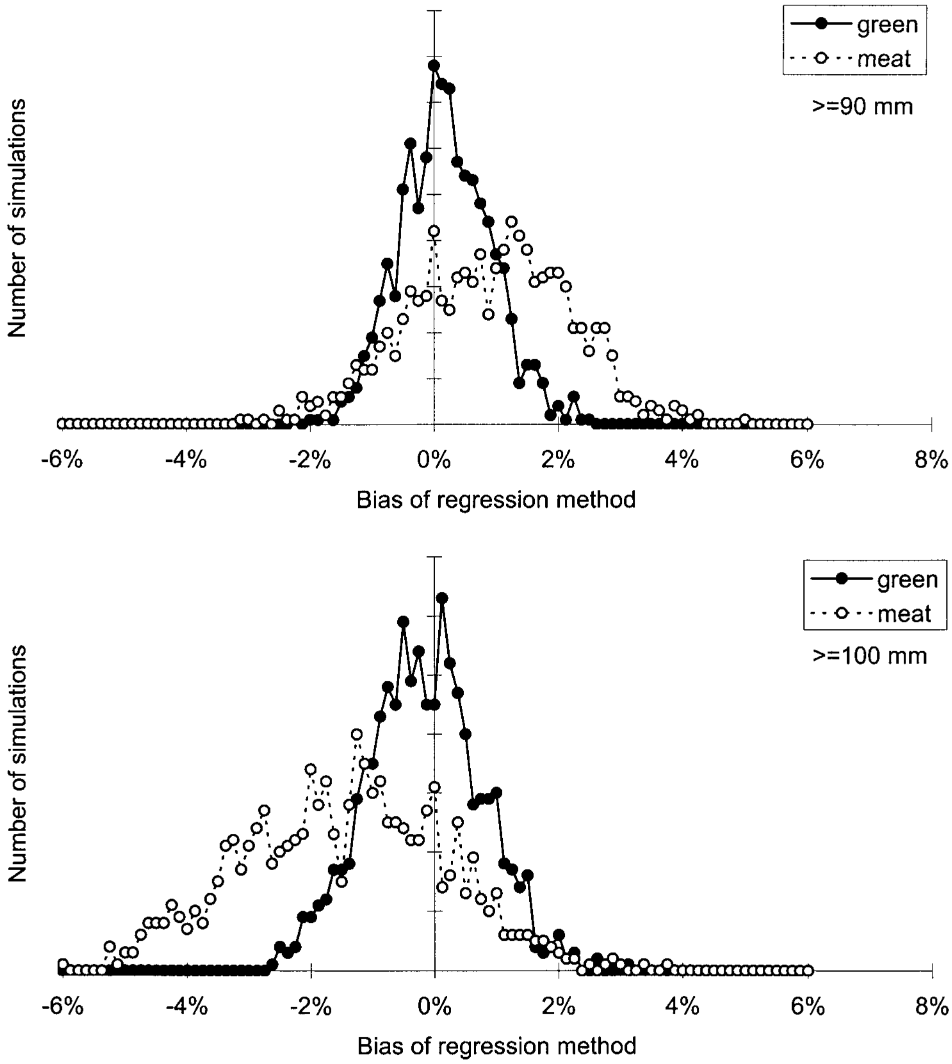

***Figure 4*: Frequency distributions of the bias from the use of a log-log regression to estimate the mean weight of a sample of scallops from their lengths: 1000 simulations were carried out using lengths of 90 (top) and 100 mm (bottom) as the minimum for the length range over which mean weight was estimated. At each iteration, mean weight was estimated using the regression method and the raw data and the bias was estimated by comparison of the two. At each iteration, 500 scallops were drawn at random (with replacement) from the 2504 available and the average weight estimated from those over the critical size.**

Prediction of seasonal average recovery fraction

From a sample of 505 legal sized (100 mm shell length or greater) scallops collected from the Coromandel fishery between 1975 and 1996, the average recovery of saleable meats from total greenweight was 13.6% with a very wide spread (Figure 5). It was initially thought likely that the seasonal timing of collection of most of these data (at times of generally poor to average condition) would lead to this being a conservative estimate of the average recovery rate possible throughout a whole season, especially if fishing is concentrated on populations that are in good condition. However, detailed examination of estimated greenweight and actual landed meatweight for the Coromandel fishery (from CELRs) suggests that, in fact, the seasonal average recovery has been close to 13.5% for the last three years, although there are highly significant differences among years ($F_{2,8949} = 29.71$, $p < 0.001$) and among weeks of the year ($F_{30,8949} = 4.71$, $p < 0.001$).

The seasonal pattern of recovery fraction has been inconsistent. Fishers tend to "spell" beds where spawning has recently occurred because of the poor condition of the catch, and frequently move from bed to bed in search of scallops in good condition and/or at high density. Only when all scallops in the fishery are in poor condition are such scallops taken and landed.

There is also good reason to suppose that changes to MLS for Coromandel scallops may have altered the likely attainable recovery fraction by including scallops of 90–99 mm in the fished population. During an intensive study of the impact of dredges on scallops in November and December 1996 (Cryer & Morrison 1997), almost 2000 scallops were weighed and measured, and analysis of the data strongly suggests that recovery fraction increases with scallop size (t test for departure of slope from zero, $t_\infty = 19.8$, $p < 0.001$). The difference can be quite substantial: in this sample (at a time of normally good condition) average recovery rates of 16.7% in scallops of 100–109 mm contrasted with average recovery rates of 15.6% for scallops of 90–99 mm. Thus, although the average recovery of 13.6% for scallops of 100 mm or greater might be conservative on a seasonal basis (as it was derived using data primarily from times of historically poor recovery), it is likely to be optimistic with regard to the size of scallops (as it was derived using data from scallops of 100 mm or greater, and the inclusion of smaller scallops of 90–99 mm can be expected to lead to poorer recovery rates).

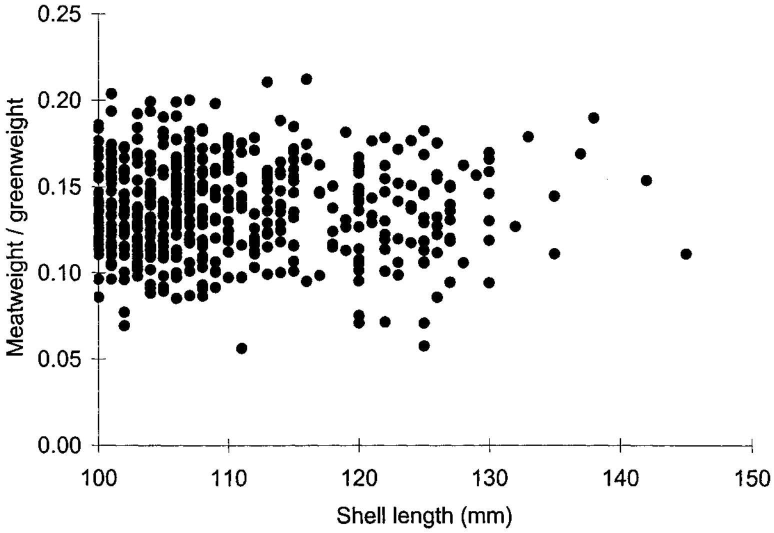

***Figure 5*: Recovery fraction (meatweight divided by greenweight) for a sample of 505 scallops of 100 mm or greater shell length from the Coromandel fishery between 1978 and 1995. The average recovery fraction for this sample was 13.5%.**

There is much less information available to examine the likely recovery fraction for Northland scallops, although the larger average size in this fishery suggests that recovery is more likely to be higher than it is to be lower than in the Coromandel fishery. In addition, the overall average recovery fraction estimated from CELR data (1995 to 1997 seasons) was significantly greater than that for the Coromandel fishery ($F_{1,8949} = 62.68$, $p < 0.001$) at a little over 14%. Unfortunately, a considerable proportion of fishing in the last three years was done in Spirits Bay where the average size and condition of scallops were exceptionally high, and this may bias the results with respect to an "average" year where fishing is more widespread. Thus it is not known whether an assumed average recovery fraction of 13.5% is likely to be conservative for the Northland fishery.

Coromandel pre-season survey

Dredge efficiency estimates

Dredge efficiency experiments were carried out at Waiheke Island in 1998 because of the paucity of information for this (muddy or silty) bottom type. There density of scallops of all sizes was high, facilitating the use of divers working relatively short search transects in deep water (about 24 m). Apparent efficiency of the dredge for scallops of shell length greater than 90 mm varied from 16.6% to 48.8% at these four sites (Figure 6), with the usual pattern of increasing efficiency with increasing scallop size (other than for a very high and unexplained apparent efficiency for scallops of about 60 mm shell length at one of the sites).

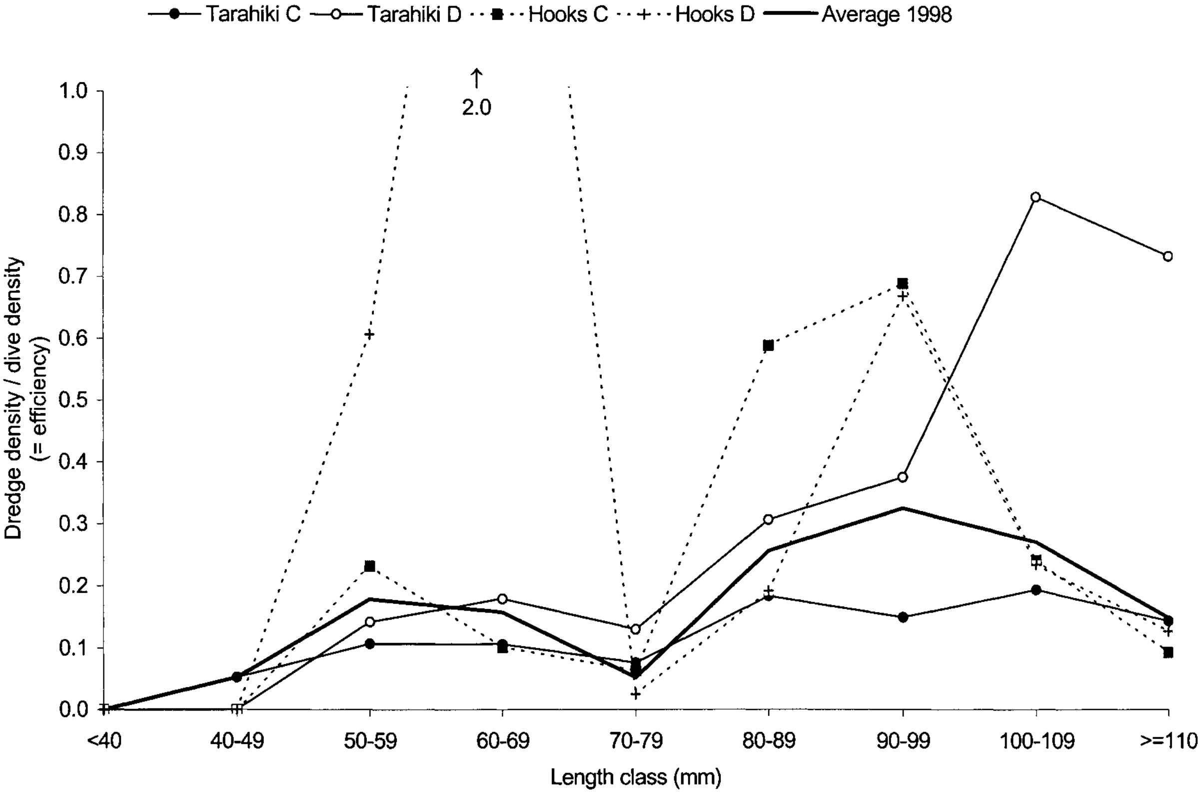

***Figure 6*: Approximate dredge selectivity curves for M.F.V. *Kataraina* working at Waiheke Island in 1998. The "average" line is estimated using the average of the reciprocals of efficiency, not the average of the observed efficiency estimates. Estimated efficiency for scallops 90 mm or larger at each of the sites varied from 17 to 49%.**

Table 1: **Pooled estimates of dredge efficiency for all scallops of 90 mm or more in length from experimental areas on sandy (A) and muddy (B) substrates in the Coromandel fishery. The same dredge deployed from survey vessels *L'Aries* or *Kataraina* were used, these vessels being of very similar size, weight, horsepower, and propeller design**

Site	Year	Density by dredge	Dredge shots (n)	Density by dive	Dive sites (n)	Efficiency (%)	Derived multiplier
A: on sand							
Opito A	1993	0.0250	2	0.0700	4	35.71	2.80
Opito B	1993	0.1825	2	0.6812	4	26.79	3.73
Opito C	1993	0.0760	2	0.2610	4	29.16	3.43
Opito A	1994	0.0286	2	0.0860	4	33.26	3.01
Opito C	1994	0.0340	2	0.0669	4	50.82	1.97
Opito A	1995	0.0530	3	0.0688	4	77.03	1.30
Opito B	1995	0.0196	3	0.0711	4	27.57	3.62
Opito C	1995	0.0797	3	0.2014	4	39.57	2.53
3 Mile Bank	1996	0.0225	3	0.0417	9	53.96	1.85
Opito D	1996	0.0410	6	0.0729	17	56.24	1.78
Opito A	1997	0.0679	4	0.1160	4	58.53	1.71
Opito C	1997	0.1068	4	0.1613	4	66.21	1.51
Mean (sand)						46.24	2.437
c.v. (sand)							10.2%
B: on mud							
Tarahiki A	1984	0.1141	11	0.5467	3	20.87	4.79
Tarahiki B	1985	0.2290	16	0.5587	7	40.99	2.44
Hooks A	1991	0.0865	2	0.1933	5	44.75	2.23
Hooks B	1991	0.0872	2	0.1245	5	70.04	1.43
Tarahiki C	1998	0.1133	1	0.6799	4	16.66	6.00
Tarahiki D	1998	0.1323	1	0.2985	4	44.32	2.25
Hooks C	1998	0.1941	1	0.3981	3	48.76	2.05
Hooks D	1998	0.3128	1	0.7557	4	41.39	2.42
Tarahiki E	1999	0.0034	1	0.0170	4	19.74	5.07
Hooks E	1999	0.0109	1	0.0306	4	35.83	2.79
Hooks F	1999	0.0450	1	0.1167	4	38.58	2.59
Mean (mud)						40.97	3.096
c.v. (mud)							14.4%

Pooled length frequency distributions

Pooled length frequency distributions corrected for dredge efficiency and scaled to estimated population size are shown for the six major areas of the Coromandel fishery in Figures 7–9. These scaled distributions are only approximately comparable with estimates of numbers of scallops of over 95 mm in shell length because the mechanism of correcting for dredge selectivity (by 10 mm size classes) differs from that used to correct for overall efficiency for scallops likely to recruit (single size class with a variance).

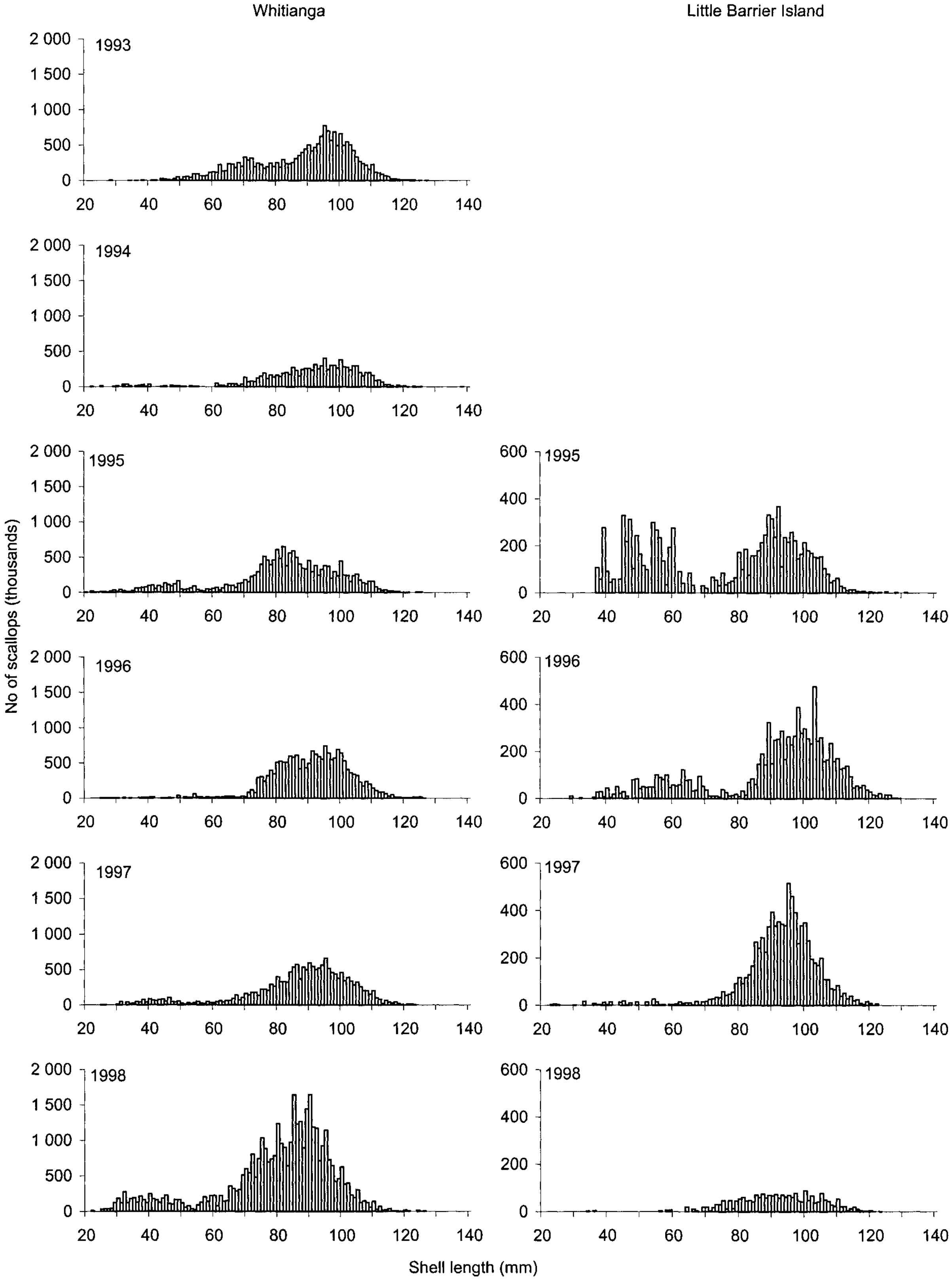

Figure 7: **Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected for dredge efficiency. Left, Whitianga and environs; right Little Barrier Island.**

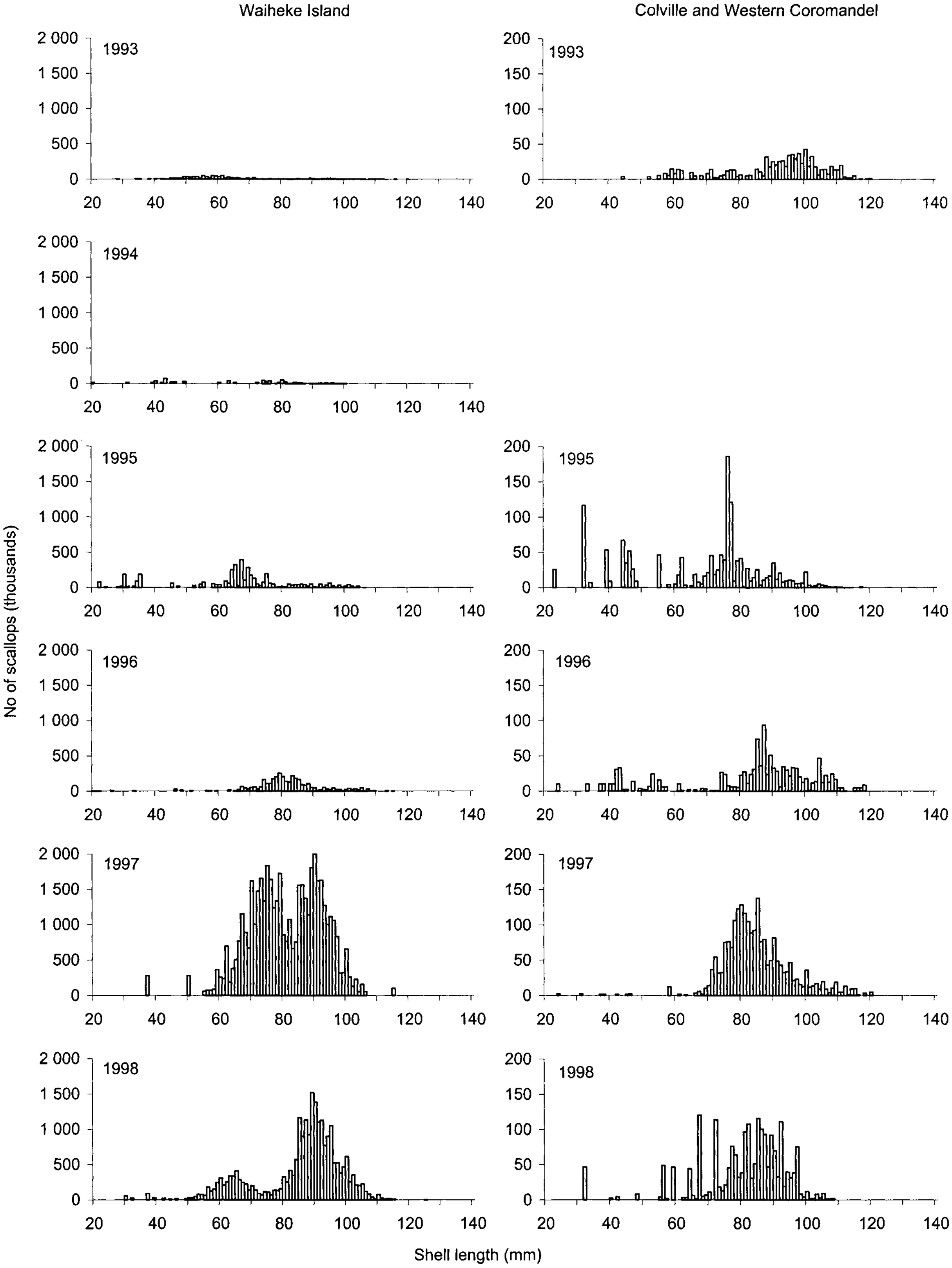

Figure 8: **Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected for dredge efficiency. Left, Waiheke Island; right, Colville and western Coromandel Peninsula.**

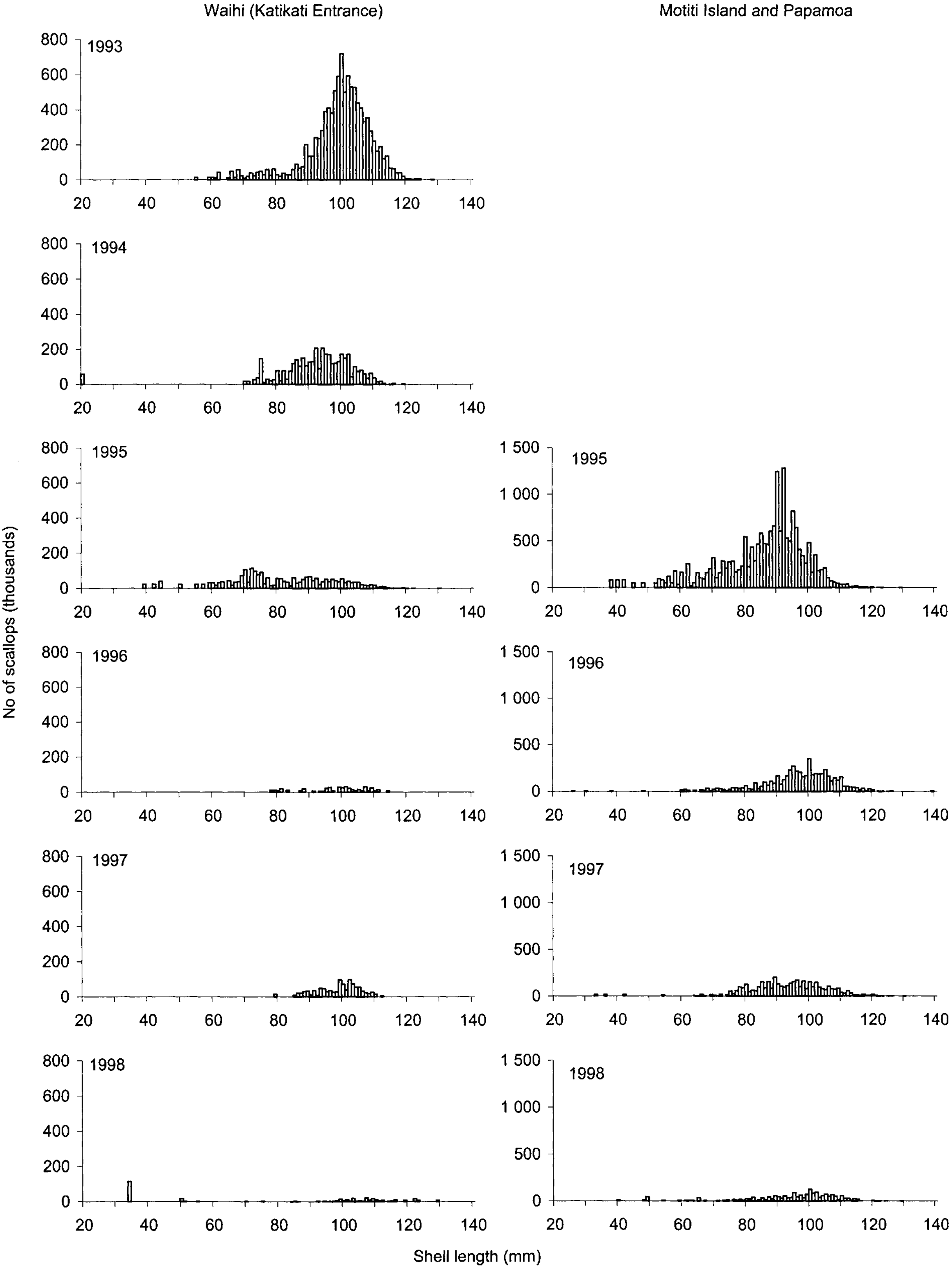

Figure 9: **Approximate scaled length frequency distributions (thousands of animals) for the Coromandel scallop fishery, corrected for dredge efficiency. Left, Waihi (Katikati Entrance); right, Motiti Island and Papamoa Beach.**

Density and biomass estimates

Estimates of mean density, population abundance, and approximate standing biomass at the time of the survey are given in Table 2 for the Coromandel fishery. Of about 68 million scallops estimated to be within the survey area of 341 km^2, 14.2 million (21%, range 10–61% by area) were of a size at which they were likely to achieve a length of 100 mm by the start of the season.

***Table 2*: Summarised results of abundance surveys for scallops in the six major areas within the Coromandel fishery surveyed during 1998. Data for strata at Shoe and Slipper Islands are not tabulated separately but are included in the "Fishery" total. The recruited population size is the estimated number of scallops 95 mm or greater shell length at the time of the survey, it being assumed that all such scallops will grow to 100 mm by the start of the season in July. Mean weight of recruits is estimated as the mean weight of all individuals of 100 mm shell length or greater at the time of the survey**

Bed	Total population size ($*10^{-6}$)	Recruited population (> 95 mm)	Recruited density (m^{-2})	*c.v.* of recruited density	Mean recruit weight (g)	Approx. biomass (t)
Whitianga	37.95	6.44	0.0786	0.15	99.6	641
Waihi	0.36	0.11	0.0019	0.32	108.3	12
Motiti	1.90	1.16	0.0121	0.40	103.1	120
Barrier	2.22	0.96	0.1116	0.28	103.5	99
Waiheke	23.39	5.25	0.1129	0.34	96.4	506
Colville	2.00	0.20	0.0054	0.50	95.9	19
Fishery	67.81	14.21	0.0416	0.16	99.4	1 414

Growth rates

Tagging studies conducted by Fisheries Management Division in the 1980s, by MAF Fisheries (1992–95), and by NIWA contracted to MFish (1995–96 to 1997–98) have generated data from both Coromandel and Northland fisheries and from a wide variety of locations and depths. Substantial numbers of returns have been received from Whitianga, Little Barrier Island, Bream Bay, Doubtless Bay, and Rangaunu Bay. The return rate of tags has been low (less than 5%) compared with the probable exploitation rate of the stocks (about 50%), possibly because of the very small tags.

Walshe (1983) estimated growth rates in Hauraki Gulf and Bay of Plenty populations by tagging using Ricker's method (Ricker 1975). He found large differences in both K (1.20 *vs.* 0.38, respectively) and L_∞ (115.9 *vs.* 140.6, respectively). Unfortunately, the raw data for these analyses cannot be found.

Analysis of tag returns from Whitianga in the 1980s (unpublished data of L.G. Allen) and throughout the Coromandel and Northland fisheries in the 1990s (MAF Fisheries and MFish data) using the more sophisticated GROTAG likelihood method of Francis (1988) suggests that average, fishery-wide growth may vary considerably among years. In 1982 and 1983, K was estimated to be about 1.20, but in 1984, growth was very poor, and K was estimated to be about 0.60 (Table 3). There are insufficient data for the 1990s to examine between-year variation in growth but, over the whole period, K was estimated to be about 1.40 (Figure 10). Where bootstrap estimates of error have been conducted using these data, the *c.v.* of K has been about 10%, while that of L_∞ has been much less at about 2–5%. Given these likely errors, the differences between average growth rates from the 1980s and 1990s are not likely to be significant, other than for the unusual year of 1984.

***Table 3*: Parameters of von Bertalanffy growth equations estimated by the GROTAG method using tag-recapture data from three years in the Whitianga scallop population (unpublished data of K.A.R. Walsh and L.G. Allen), from throughout the Coromandel and Northland fisheries between 1992 and 1997, and from Whitianga and Bream Bay recoveries from depth ranges 0–15, 16–25, and 26–35 m (Whitianga) or < 20 m and > 20 m (Bream Bay). The assumed parameters p = 0.01 and s = 2.00 (proportion of contamination by outliers and the standard deviation of measurements) come from repeat measurements by six research staff in 1996, g40 and g95 are the estimated average annual increments for scallops of 40 and 95 mm, respectively, at tagging, u and w describe the estimated amplitude and phase of seasonal fluctuation in growth, and L_∞ and *K* are the estimated parameters of von Bertalanffy growth equations**

		GROTAG parameters				von Bertalanffy	
Year	N	g40	g95	u	w	L_∞	*K*
1982 Whitianga	69	52.40	13.81	-0.600	0.324	114.7	1.210
1983 Whitianga	596	47.50	9.13	-0.286	0.539	108.1	1.197
1984 Whitianga	147	30.32	5.94	-0.901	0.611	108.4	0.586
1992–97 all data	227	51.40	11.09	0.792	0.779	109.8	1.392
1992–97 Coromandel only	138	49.86	10.26	0.667	0.790	108.8	1.366
1992–97 Northland only	89	52.88	11.70	0.793	0.727	110.6	1.382
Whitianga, mean 10.6 m	34	60.07	15.12	0.412	0.880	113.5	1.700
Whitianga, mean 21.1 m	63	33.66	6.83	2.798	0.632	109.0	0.669
Whitianga, mean 29.7 m	31	31.24	6.79	7.206	0.437	110.3	0.588
Bream Bay, mean 18.4 m	28	52.99	8.81	2.425	0.779	106.0	1.626
Bream Bay, mean 21.4 m	24	50.56	11.37	1.459	0.420	111.0	1.247

However, when the data are segregated by depth at release, strong patterns in the estimates of *K* appear, with scallops released into shallow water (less than about 15 m) showing much faster growth than those released into deeper water (depth ranges averaging 20 and 30 m). Given the likely errors, the differences between average growth rates in shallow and deep water are highly likely to be significant. Inspection of the distribution of residuals (Figure 11) also implies a relationship between release depth and expected growth in the Coromandel fishery, but not for the Northland fishery (where there is much less contrast in the release depth). Only at Whitianga and Bream Bay are there sufficient tag returns to conduct such analyses, and the data for Bream Bay come from a relatively narrow depth range. The patterns in L_∞ are much less apparent, and the differences among years quite small, although Whitianga scallops released into shallow water gave the largest estimate of L_∞, which is against expectation given the usual negative correlation between *K* and L_∞.

The apparent high variability of growth rate with depth and among years suggests that estimating average fishery-wide growth rate may be inappropriate, especially when estimating start of season biomass from a pre-season biomass survey. For example, the expected annual growth increment of a scallop of 95 mm shell length (g95) varied from about 6 to 14 mm (by year) in the 1980s, and from about 7 to 15 mm (by depth) in the 1990s. The current assumption used when estimating start of season biomass is that any scallop of 95 mm shell length at the time of the survey will probably have grown to 100 mm by the start of the season about 3 months later. For a scallop in deep water in a season of poor growth, the annual expectation of growth may be less than 5 mm, and the growth over 3 (autumn-winter) months may be negligible. Thus, the distribution by depth of scallops just under the minimum legal size and growth conditions in a given year may be critical in determining the extent to which the assumed critical size (of 95 mm) is appropriate in that year.

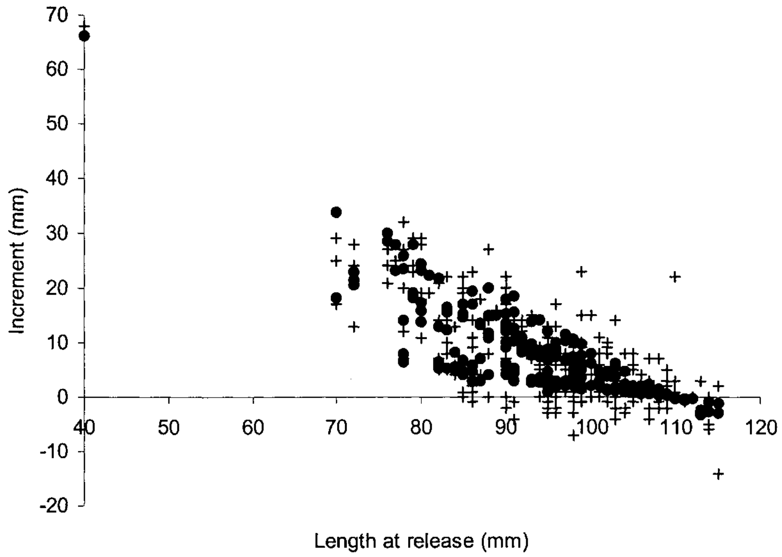

***Figure 10*: Modelled (closed circles) and observed (crosses) increments at length in a pooled GROTAG model for Northland and Coromandel scallops tagged between 1992 and 1997.**

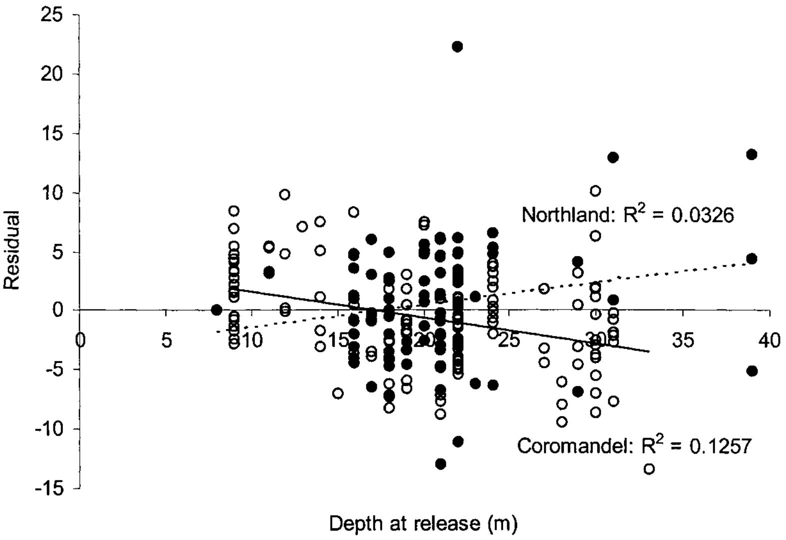

***Figure 11*: Plot of residuals from a pooled GROTAG analysis against release depth for scallops tagged in the Coromandel fishery (open circles, solid line) and Northland fishery (closed circles, dashed line) between 1992 and 1997. There is no significant relationship for the Northland fishery ($p > 0.05$) and a highly significant negative relationship ($p < 0.0001$) for the Coromandel fishery, implying a negative relationship between depth and rate of growth in that fishery.**

Multiple length frequency analysis (using MULTIFAN) has produced estimates of K which are broadly consistent with the tagging estimates, although there is a large amount of variation. Estimates of L_∞ made using length frequency analysis have usually been lower than those given here, although this could be an artefact of this method applied to a fishery with high size-related (as opposed to age-related) fishing mortality. MULTIFAN estimates are not presented here because they are not thought to be realistic.

Start of season recruited biomass at 100 mm shell length

To predict start of season recruited biomass, assumptions about growth and mortality between the time of survey and the start of the season must be made. The mid date for surveys of the Coromandel fishery was about mid May, about 50 days before the start of the 1998 season (nominally 15 July). During that period, it has hitherto been assumed that most scallops of 95 mm or more in shell length would grow to 100 mm. Given the analyses presented above, however, this estimate of the start of season biomass may be sensitive to the depth distribution of scallops just below the minimum legal size and to the (probably unpredictable) growth conditions in 1998. In the absence of analysis and modelling of the consequences of this sensitivity, the assumed critical size of 95 mm is used here (i.e., it is assumed all scallops of 95 mm or greater shell length at the time of the survey will be at or above the minimum legal size by the start of the season).

Assuming a natural mortality rate of $M = 0.40$ spread evenly over the year, leads to an absolute mortality of about 5.4% for the period between survey and season for the Coromandel fishery.

Recruited biomass, using Equation (5), is essentially the product of the abundance of scallops over 95 mm shell length at the time of the survey, their expected average weight at the start of the season, and their expected survival rate of 94.6%. For the surveyed beds in the Coromandel fishery in 1998, this equates to

$$14.2*10^6 * 99.55 * 0.946 = 1337 \text{ t (greenweight), or}$$

$$\text{assuming 13.5\% recovery, } 1337 * 0.135 = 180 \text{ t (meatweight)}$$

These estimates both have a *c.v.* of 15.8% 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.

Start of season recruited biomass at 90 mm shell length

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 management plan agreed at that time adopted an assessment regime whereby the calculated available yield would be based on the abundance and biomass of scallops greater than 100 mm shell length, pending research on dredge impacts and more appropriate methods of estimating yield. That management plan has expired and it may now be an option to adopt a yield estimation method based on the new MLS of 90 mm and the recruited biomass at that size. Again, in the absence of any analysis or modelling of the implications of variability in growth rates among years and by depth, it is here assumed that all scallops of 85 mm or greater length will grow to 90 mm between the survey and the start of the season.

Recruited biomass at a MLS of 90 mm, using Equation (5), is essentially the product of the abundance of scallops longer than 85 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 94.6%. For the surveyed beds in the Coromandel fishery in 1998, this equates to

$$35.2*10^6 * 81.20 * 0.946 = 2702 \text{ t (greenweight), or}$$

$$\text{assuming 13.5\% recovery, } 2702 * 0.135 = 365 \text{ t (meatweight)}$$

These estimates both have a *c.v.* of 15.5% 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.

The impact of Voluntary Closed Areas on start of season recruited biomass

Voluntary Closed Areas (VCAs) were an integral part of the management plan for Coromandel scallops which was in force between 1995 and 1997. Commercial fishers agreed not to fish in certain areas of high interest to recreational fishers in return for the support of the latter groups for other parts of the plan, especially the reduction in MLS to 90 mm. The plan also stipulated that scallops within voluntary closures be included in biomass and yield estimates. Following the expiry of the management plan, the VCAs were to be renegotiated and it has been suggested that the biomass of scallops within any agreed closures might be excluded from total biomass and yield calculations. Without in any way prejudging this issue, the impact on total fishery area and recruited biomass of VCAs proposed by commercial and recreational user groups is examined here.

VCAs put forward by recreational user groups in the Coromandel fishery amount to 50.4 km^2 out of a total surveyed fishery area of 341.2 km^2 (14.8% of the total area). Removal of these areas (and their associated sample stations) from the analysis of scallop abundance and biomass suggests that about 3.3 million scallops of 100 mm or greater at the start of the season (23.6% of the total) will be contained within VCAs proposed by recreational user groups. About 6.2 million scallops of 90 mm or greater at the start of the season (17.8% of the total at this size) are likely to be contained within VCAs proposed by recreational user groups (Appendix 4).

Voluntary closed areas put forward by commercial fishers in the Coromandel fishery amount to 10.6 km^2 out of a total surveyed fishery area of 341.2 km^2 (3.1% of the total area). Removal of these areas (and their associated sample stations) from the analysis of scallop abundance and biomass suggests that about 0.2 million scallops of 100 mm or greater at the start of the season (1.3% of the total) will be contained within VCAs proposed by commercial fishers. About 0.5 million scallops of 90 mm or greater at the start of the season (1.5% of the total at this size) are likely to be contained within VCAs proposed by commercial fishers (Appendix 5).

The impact on the estimated start of season recruited biomass of scallops of the VCAs proposed by commercial and recreational users in the Coromandel fishery is shown in Table 4.

Table 4: **Estimated recruited biomass (t, greenweight) of scallops above minimum legal sizes of 100 and 90 mm in the Coromandel fishery as surveyed and when voluntary closed areas (VCAs) proposed by commercial fishers and by recreational users are excluded from the survey area.**

			Start of season biomass (t)
Minimum legal size (mm)	Total fishery	Commercial VCAs excluded	Recreational VCAs excluded
100	1 337	1 320	1 021
90	2 702	2 661	2 221

Sampling of Coromandel landings in 1997 and 1998

From 64 landings in 1997 and 101 landings in 1998, we measured a total of 59 977 scallops (23 477 and 36 500 in the two years, respectively) (Table 5). The target number of landings sampled was met or exceeded in 6 of the 9 months of sampling, but was not approached closely in August or October of 1998 because of the very low level of fishing effort. There were no problems organising access to landings (as has occurred in some other fisheries). Overall, 1.5% of scallops measured were under the minimum legal size of 90 mm (0.4% in 1997 rising to 1.7% in 1998) and only 6.1% measured 110 mm or more (8.8% in 1997 declining to 4.4% in 1998).

Table 5: **The number of landings sampled, the number of bins of scallops selected for measuring, the total number of bins of scallops in the landings selected, and the total number of scallops measured in each of six 5 mm size classes during the 1997 and 1998 Coromandel seasons**

				Number of scallops measured in each size class (mm)						
	Landings sampled	Bins sampled	Total bins landed	<90	90–94	95–99	100–104	105–109	>=110	Total
Oct-97	21	21	261	11	1 300	2 440	1 948	1 050	619	7 368
Nov-97	21	21	253	29	1 319	2 238	1 983	1 371	836	7 776
Dec-97	22	22	289	65	1 879	2 738	1 968	1 070	613	8 333
Jul-98	19	19	447	113	1 727	2 428	1 538	677	273	6 756
Aug-98	7	9	97	36	808	1 170	636	210	116	2 976
Sep-98	23	23	223	128	2 590	2 748	1 604	623	453	8 146
Oct-98	12	12	111	82	1 576	1 410	800	314	151	4 333
Nov-98	20	20	125	109	1 925	2 547	1 673	754	425	7 433
Dec-98	20	20	136	308	2 566	2 117	1 180	492	193	6 856
Total	165	167	1 942	881	15 690	19 836	13 330	6 561	3 679	59 977

The overall length frequency of scallops measured by month (weighted by the number of bins in each landing) is shown in Figure 12. The two sets of length frequency distributions are qualitatively similar in that there is a tendency for the range of size classes to reduce as the season progresses. However, there are three important differences. First, the 1998 distributions have a much steeper ascending limb from the MLS of 90 mm than the 1997 distributions. Second, the 1998 distributions are narrower than the 1997 distributions. Third, scallops under the MLS of 90 mm are a significant component of landings (fleet average almost 5%) towards the end of the 1998 season.

Landings from one vessel had a particularly large mean 5 percentile size of about 95 mm during both 1997 and 1998 (Figure 13). Landings from other vessels had smaller mean 5 percentile sizes, and these tended to be higher in 1997 than in 1998: about half of the fleet had a mean 5 percentile size of about 92 mm (or more) in 1997, compared with only one vessel in 1998. In 1998, all vessels except the one already mentioned had a mean 5 percentile size very close to 90 mm. Considering this difference, the arbitrary aggregation of vessels into groups of three may introduce artefacts into subsequent analysis, most especially by partly masking the (probable) extreme behaviour of one vessel. Given the likely length frequency distribution of the population and dredge catches, perfect knife edge selection by fishers would lead to a 5 percentile size of 90 mm (occasionally 91 mm) in almost all landings. The “chipping” of a substantive proportion of scallops by rough handling might lead occasionally to a 5 percentile size of 88 or 89 mm shell length.

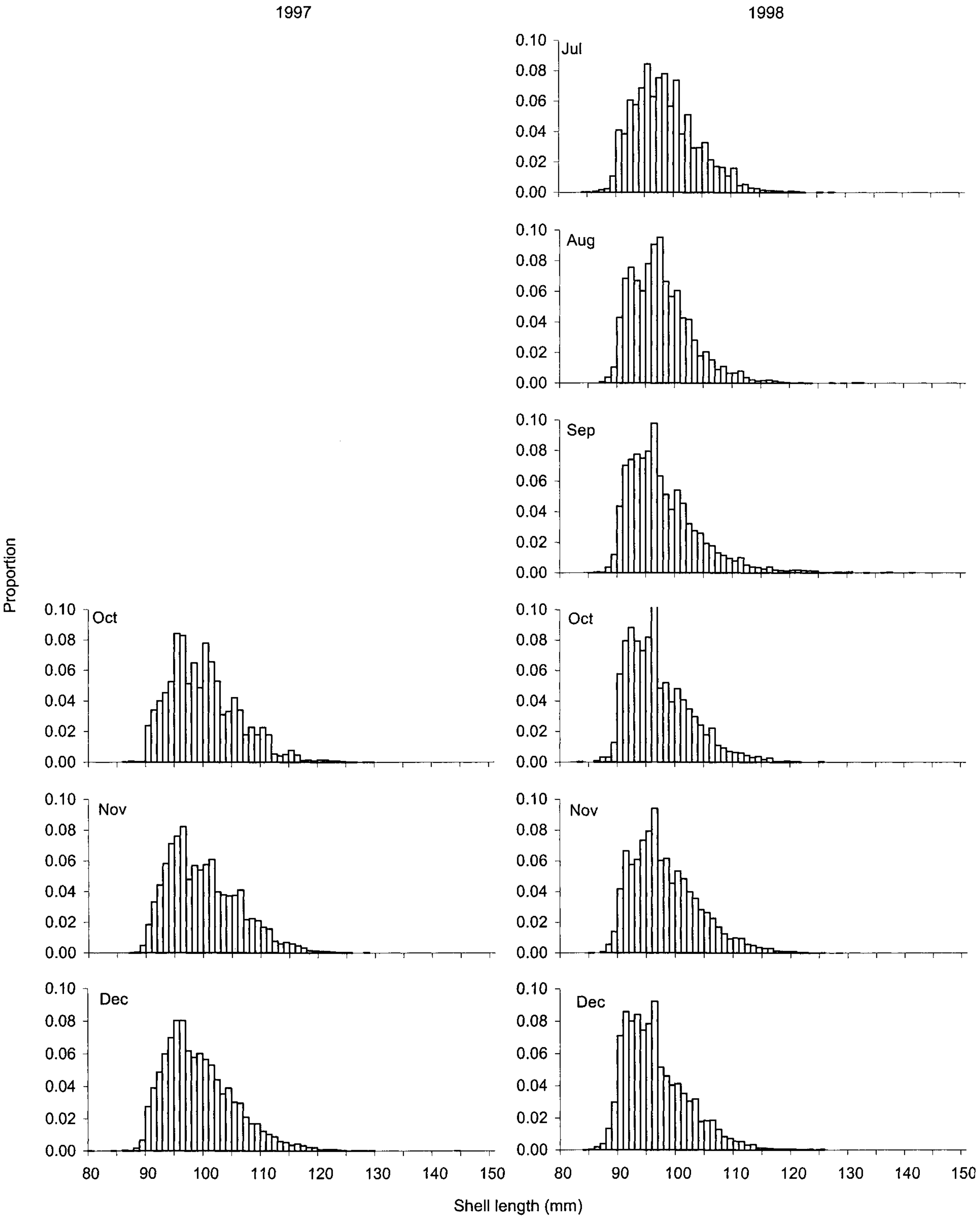

Figure 12**: Proportional weighted length frequency distributions (weights proportional to size of landing) of scallops measured in processing sheds in the Coromandel fishery in 1997 and 1998.**

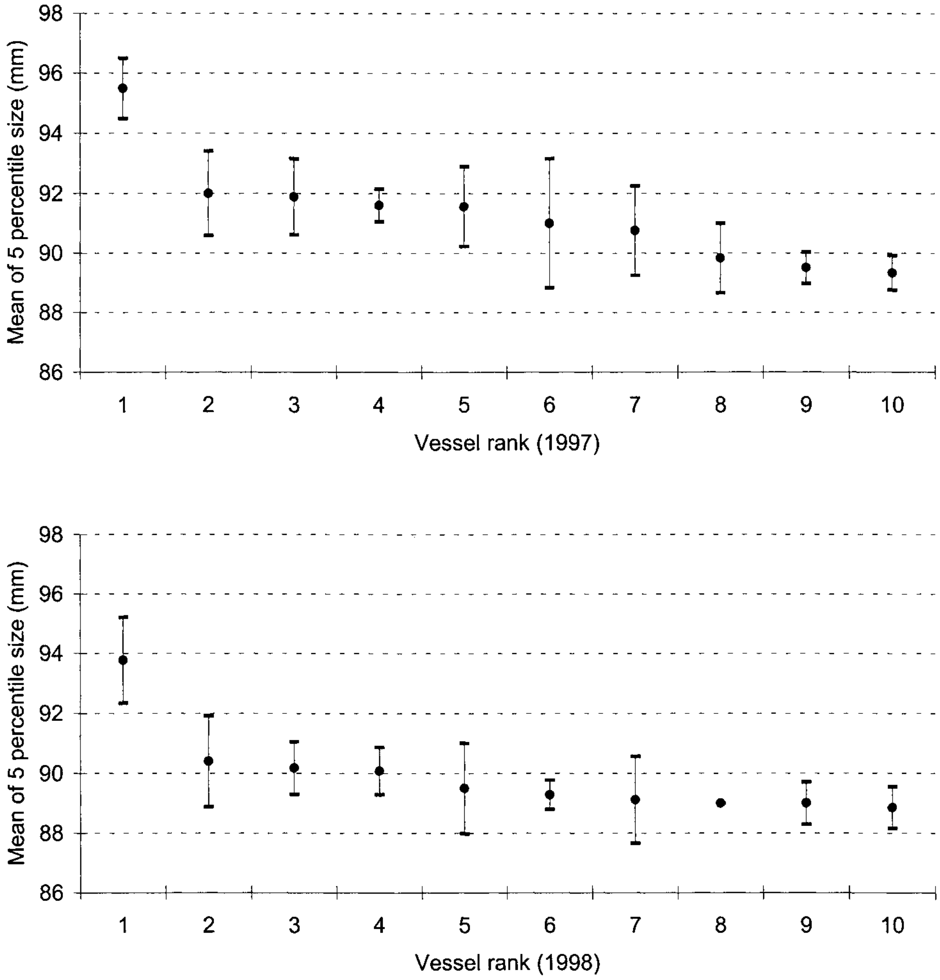

***Figure 13*: Mean (plus or minus one standard error) of the lower 5 percentile scallop length for each of 10 vessels for which at least 3 (in 1997) or 5 (in 1998) landings were sampled for length. Vessels are ranked in decreasing order of their mean 5 percentile length, but these rankings are not identical in the two years.**

The stochastic individual based model generated approximately normal length frequency distributions in 1997, and distributions with a higher left shoulder (more animals of about 80–90 mm) in 1998 (Figure 14). Moreover, the upper limit of distributions in 1998 was smaller than those in 1997, a pattern similar to that of measured landings. Applying the dredge selectivity curve to these population length frequency distributions generated very similar "expected" dredge catch distributions (Figure 15). This is not surprising as the dredge selectivity curve (Equation (15)) is quite flat between 80 and 120 mm. Finally, the application of a knife edge truncation at the MLS of 90 mm generated predicted length frequency distributions for landings in each of the months July to December in 1997 and 1998 (Figure 16).

Plots by month of the ratio between observed and expected proportion at length (Figure 17) indicate that the group of vessels with the lowest mean 5 percentile size had landings with a length frequency distribution remarkably similar (in most months) to those predicted by the sIBM and knife edge selection at 90 mm by fishers. Conversely, the group of vessels with the highest mean 5 percentile size had landings with a length frequency distribution very different from expectation, showing consistent selection against scallops in the size range 90–94 mm. The other four vessels show an intermediate pattern in 1997 (with consistent selection against scallops in the size range 90–92 mm) and a pattern very similar to the group with low mean 5 percentile size in 1998.

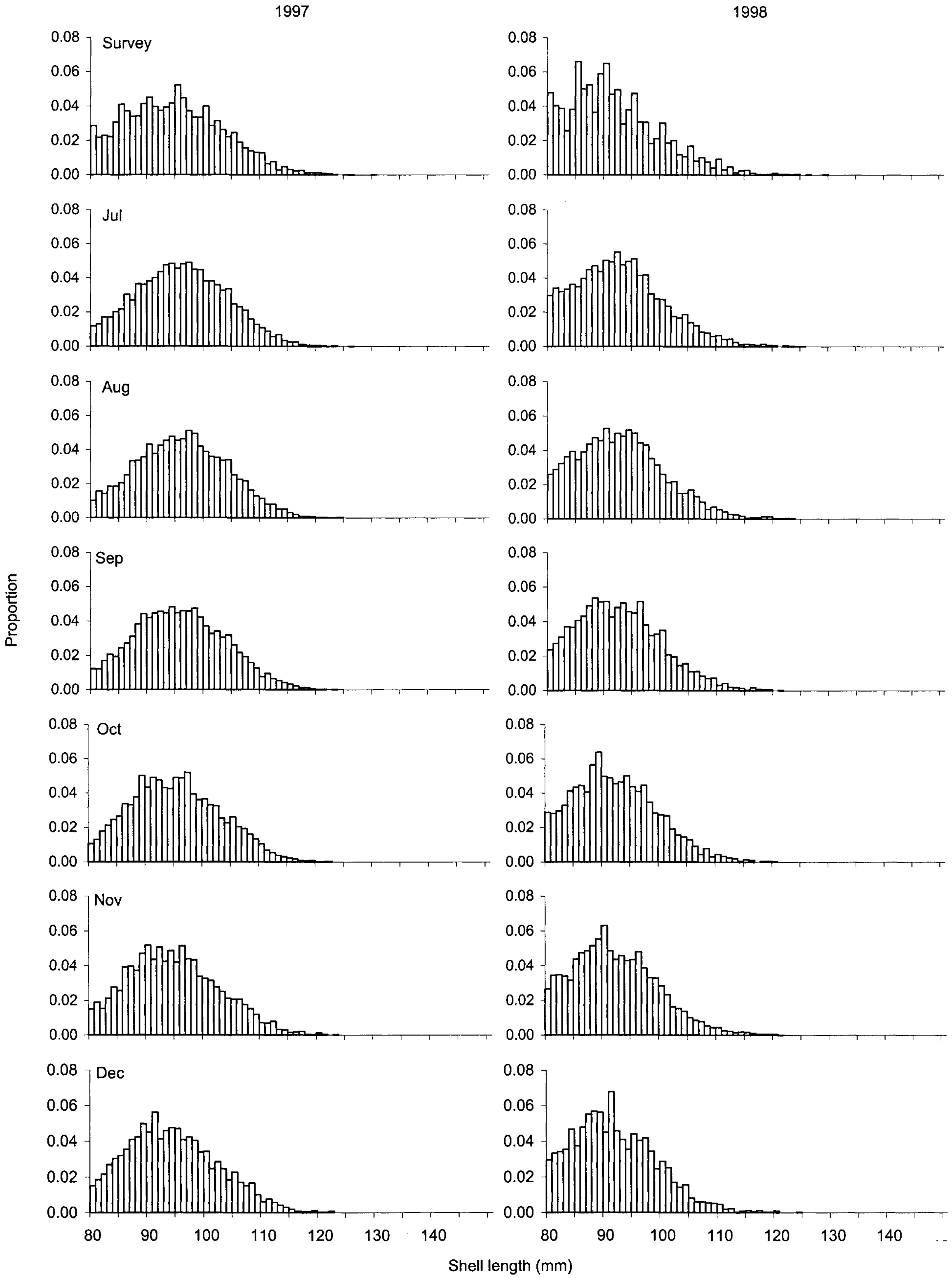

Figure 14: **Survey proportional length frequency distributions (top) for 1997 and 1998, and predicted proportional length frequency distributions for subsequent months from a stochastic individual based model. Details of modelling are in the text.**

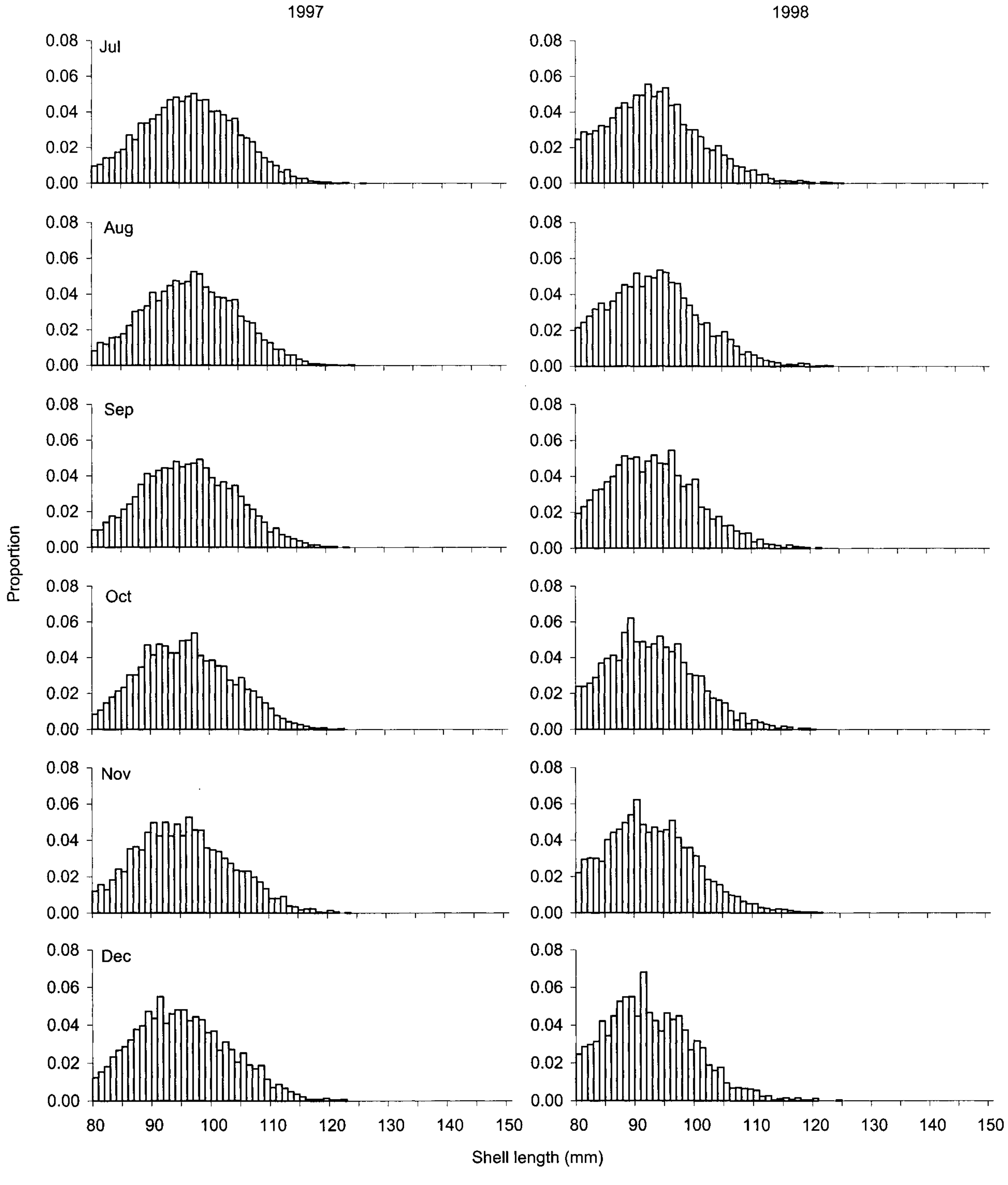

***Figure 15*: Predicted proportional length frequency distributions (from the stochastic model outputs and a fleet average dredge efficiency curve) of dredge catches in the Coromandel fishery by month in 1997 and 1998.**

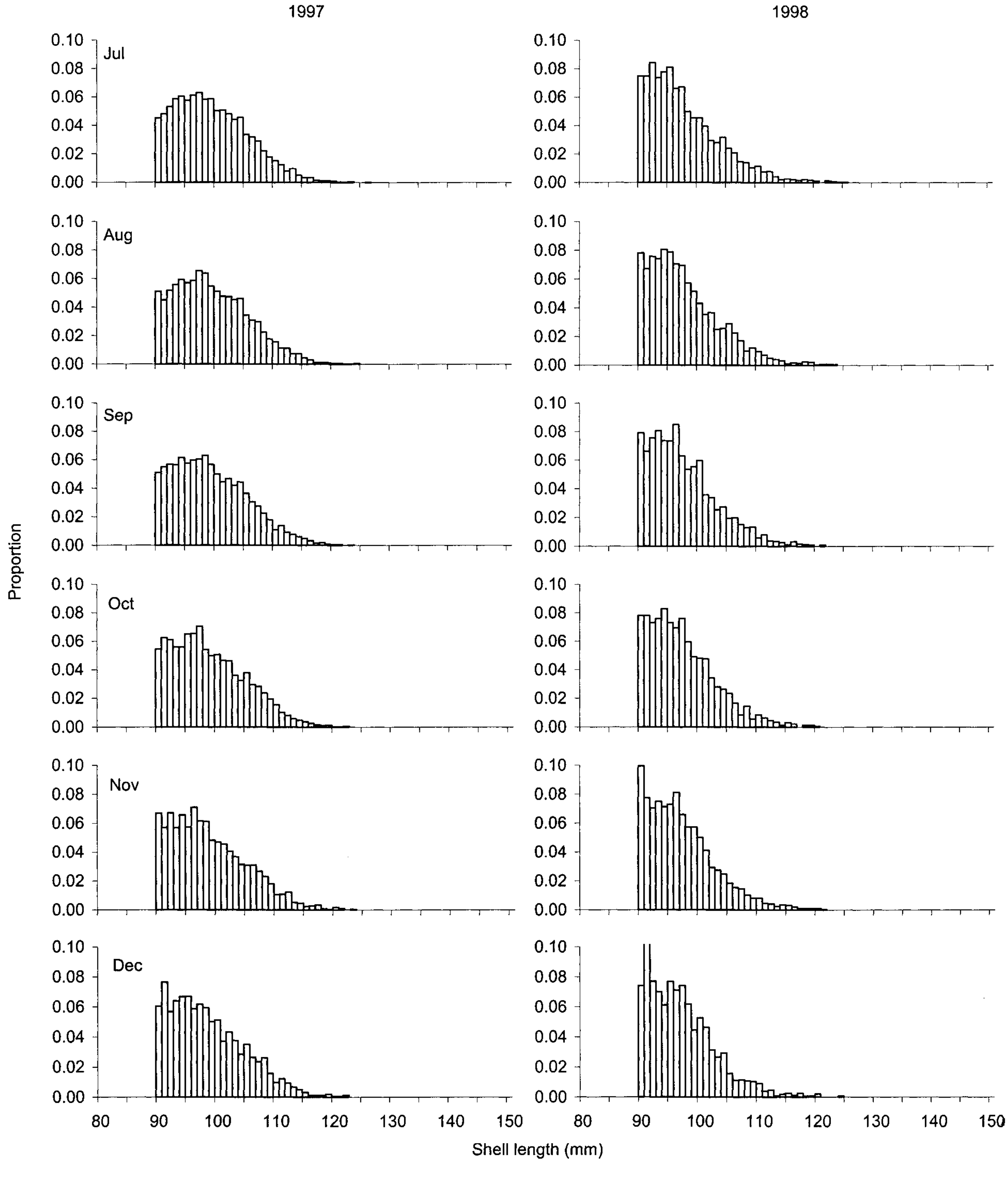

***Figure 16*: Predicted proportional length frequency distributions (from the stochastic model outputs, a fleet average dredge efficiency curve, and assumed knife edge selection by fishers at the MLS of 90 mm) of landings in the Coromandel fishery by month in 1997 and 1998.**

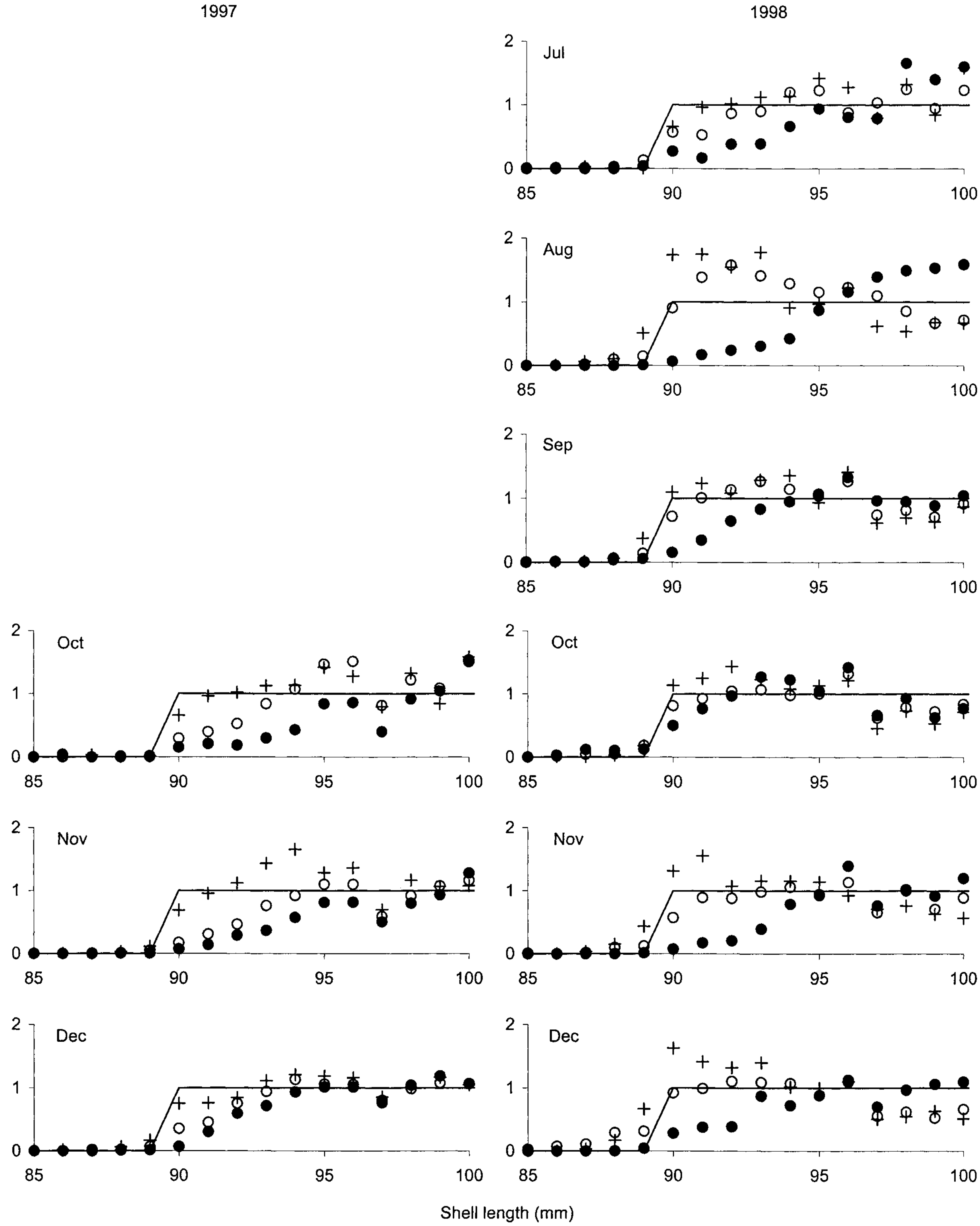

***Figure 17*: Ratio of observed to expected frequency of scallops between 85 and 100 mm in landings in the Coromandel fishery in 1997 (left) and 1998 (right). Observed frequencies were derived from measurements in processing sheds and expected frequencies were derived from a stochastic individual based model. Values of less than 1.0 indicate size classes less prevalent in landings than expected and *vice versa*. Solid circles represent data (within a given year) from the three vessels with the highest mean 5 percentile length, crosses represent data from the three vessels with the lowest mean 5 percentile length, and open circles represent the other four vessels included in the analysis. The solid line represents the expected pattern assuming knife edged selection at 90 mm. Vessels from which few landings were measured were excluded.**

Linear modelling of factors which might influence the mean 5 percentile size (which can be considered as a robust index of the smallest scallop in each landing) suggest that there are differences among vessels, among months, and between the two years, all considered as categorical variables (Table 6). The size of landings (and, by approximate inference, overall catch rate for the trip) was not influential. The most influential interaction term was that between month and vessel (increase in R^2 of about 6% compared with about 1% for other interactions), and this was found not be significant in the final model. A similar analysis on the proportion of scallops in the size range 90–94 mm gave almost identical results.

***Table 6*: Results of linear models relating the mean 5 percentile size (top) and the mean proportion of scallops in the size range 90–94 mm in landings measured in 1997 and 1998 from the Coromandel fishery to vessel, year, and month effects.**

Mean 5 percentile size	SS	df	MS	F	P
Vessel	88.26	12	7.36	7.06	<0.0001
Year	70.14	1	70.14	67.35	<0.0001
Month	20.50	5	4.10	3.94	0.0027
Month * vessel	44.13	44	1.00	0.96	0.5446
Error	105.17	101	1.04		

Proportion 90–94 mm	SS	df	MS	F	P
Vessel	0.5719	13	0.0440	6.23	<0.0001
Year	0.6343	1	0.6343	89.83	<0.0001
Month	0.1231	4	0.0308	4.36	0.0027
Month * vessel	0.2804	44	0.0064	0.91	0.6418
Error	0.7132	101	0.0071		

These results suggest that the lower end of length frequency distributions of scallop landings differ significantly by year, month, and by vessel. The year and vessel effects are very strong, although the month effect is also highly significant. There are no significant first order interaction terms, and the analysis is robust to the choice of summary variable used to describe the length frequency distribution. This suggests that the conclusions can be treated with some confidence.

Northland pre-season survey

Dredge efficiency estimates

Scallops were found to be too sparse in Matauri Bay in 1998 to make good estimates of dredge efficiency because of the very small numbers recovered by divers in the relatively small areas they can search. However, relatively dense populations off Whangaroa provided a good experimental area for a comparison with previous experiments in Northland (Table 7). Bootstrap simulations showed that dredge and dive sampling methods at Whangaroa led to very similar estimates of average scallop density, although the precision of the dredge estimate was better than that of the dive estimate (Figure 18). It was estimated, by resampling from the two bootstrap distributions of average density, that the efficiency of the box dredge deployed from *Marewa* in 1998 (for scallops 90 mm shell length or greater) was very high at about 95%, although this mean was not well estimated (Figure 19).

***Table 7*: Estimates of dredge efficiency for all scallops of length 90 mm or more from experimental areas in the Northland fishery using any survey vessel**

			Dredge		Dive		Efficiency	Biomass
Site	Year	Vessel	Density	(n)	Density	(n)	(%)	multiplier
Bream Bay	1992	*Avalon*	0.0935	6	0.1416	10	66.06	1.514
Bream Bay	1994	*Wyzanne*	0.0284	6	0.0624	9	45.41	2.202
Bream Bay	1995	*Wyzanne*	0.0340	6	0.0377	10	94.83	1.055
Rangaunu	1995	*Wyzanne*	0.0528	7	0.0585	16	90.29	1.108
Rangaunu	1996	*Ben Gunn*	0.0395	3	0.0705	3	56.03	1.784
Whangaroa	1997	*Ben Gunn*	0.0559	5	0.1179	14	47.41	2.109
Whangaroa	1998	*Marewa*	0.0239	10	0.0251	10	95.18	1.051
Mean								1.546
c.v.								9.2%

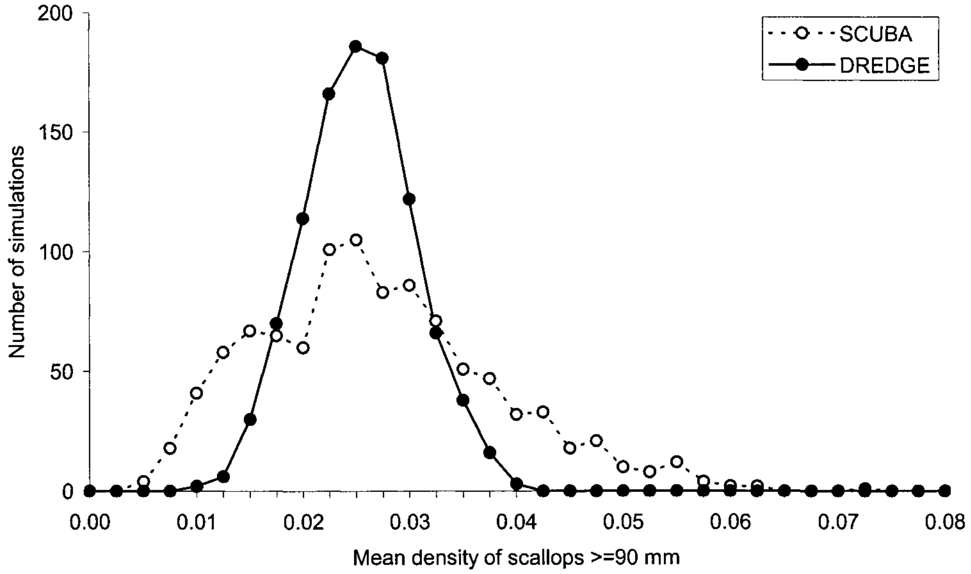

***Figure 18*: Frequency distributions of simulated sampling distributions (by bootstrap) of estimates of mean scallop density (shell length 90 mm or more) made by divers and by dredging at Whangaroa in 1998. Closed circles and solid lines, simulations using 10 dredge samples; open circles and dashed lines, simulations using 10 diver samples.**

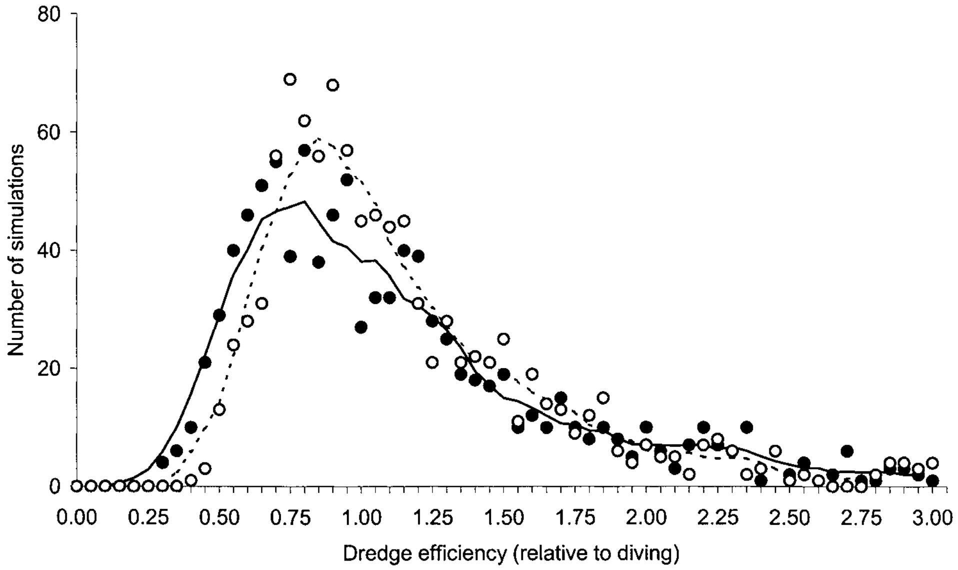

***Figure 19*: Frequency distributions (dots) with 5 pt moving means (lines) of simulated dredge efficiency for scallops of shell length 90 mm or more (bottom). Closed circles and solid lines, simulations assuming completely independent dive and dredge samples; open circles and dashed lines, simulations using paired dive and dredge samples.**

Pooled length frequency distributions

Pooled length frequency distributions corrected for dredge efficiency and scaled to estimated population size are shown for the six major areas of the Northland fishery in Figures 20–22. These scaled distributions are only approximately comparable with estimates of numbers of scallops 95 mm or greater in shell length because the mechanism of correcting for dredge selectivity (by 10 mm size classes) differs from that used to correct for overall efficiency for scallops likely to recruit (single size class with a variance). Separation of scaled length frequency distributions into smaller areas leads to small sample sizes and unreliable distributions, especially for dive strata where the area searched is smaller.

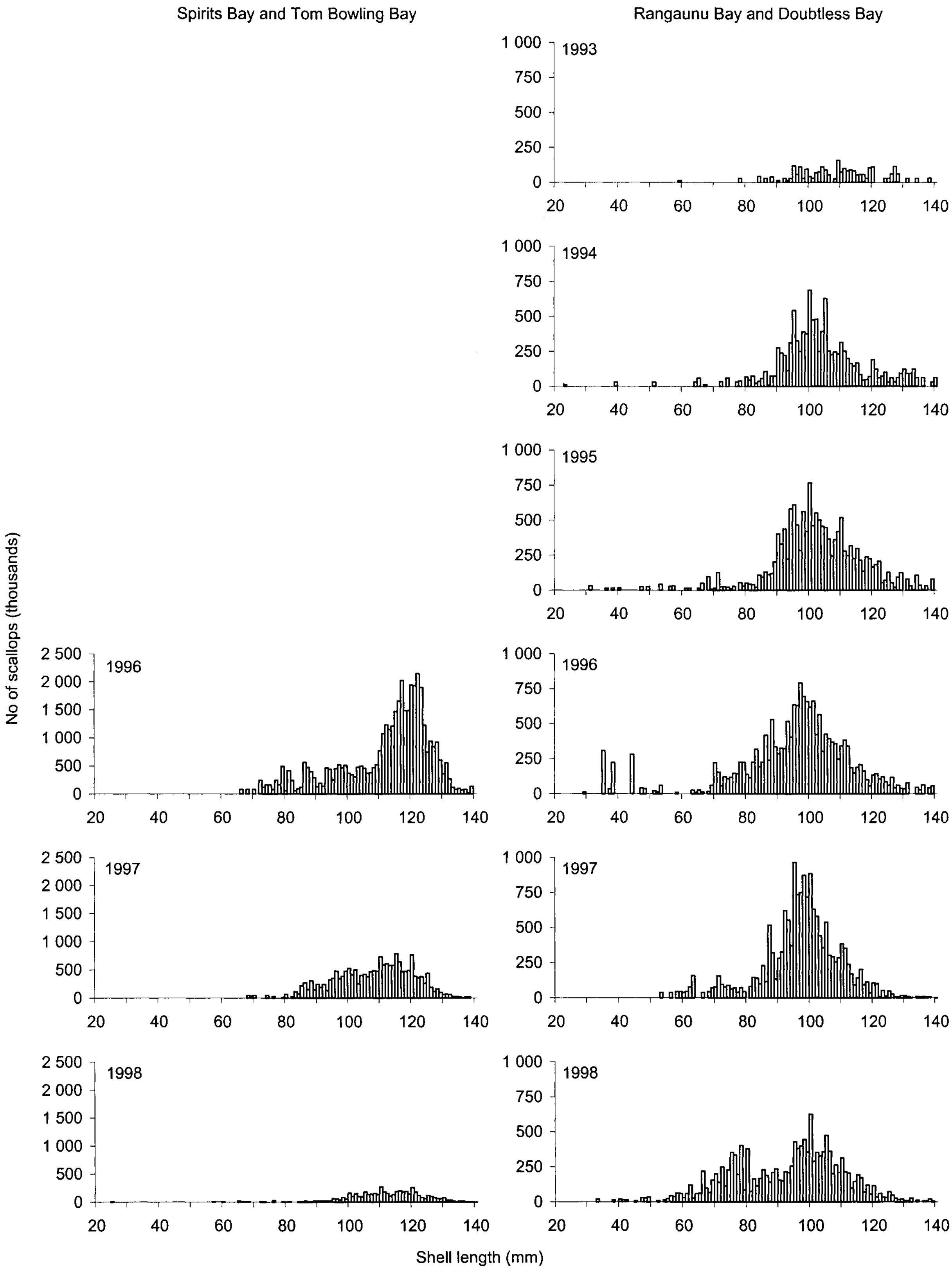

Figure 20: **Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected for dredge efficiency. Left, Spirits Bay and Tom Bowling Bay; right, Rangaunu Bay and Doubtless Bay.**

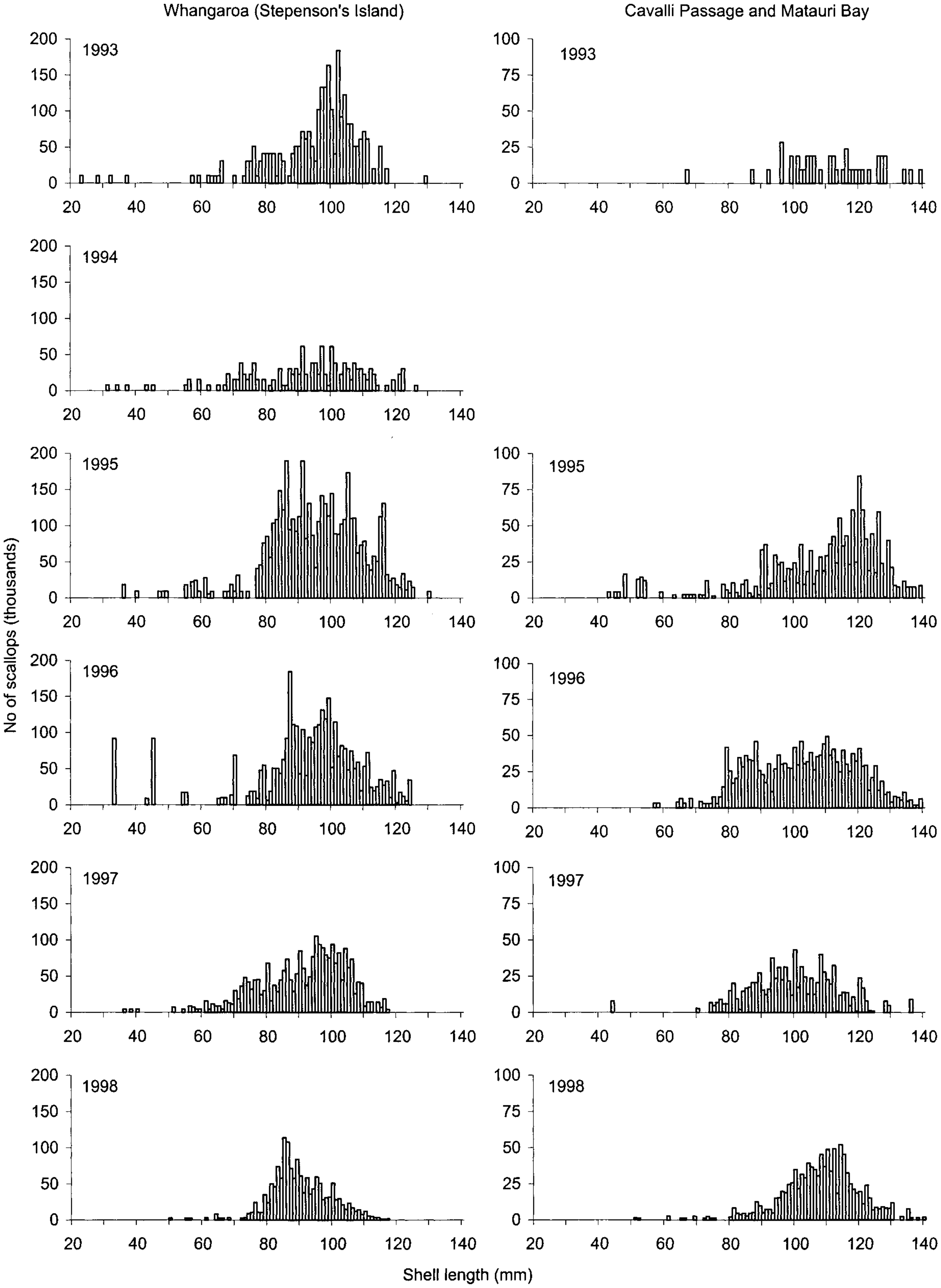

Figure 21: **Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected for dredge efficiency. Left, Whangaroa (Stevensons Island); right Cavalli Passage and Matauri Bay.**

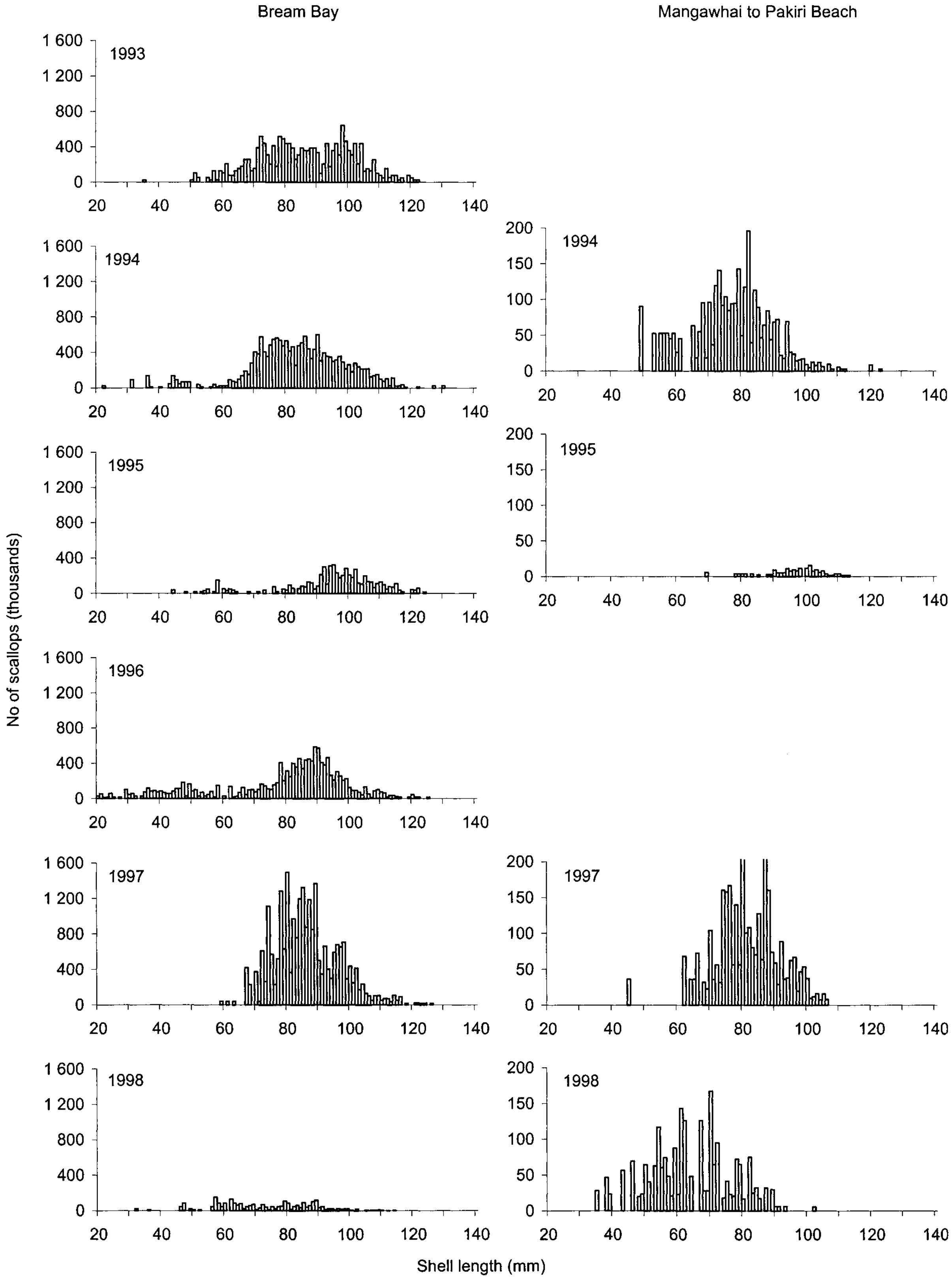

Figure 22**: Approximate scaled length frequency distributions (thousands of animals) for the Northland scallop fishery, corrected for dredge efficiency. Left, Bream Bay; right, Mangawahi to Pakiri Beach.**

Density and biomass estimates

Estimates of mean density, population abundance, and approximate standing biomass at the time of the survey are given in Table 8 for the Northland fishery. Of about 50 million scallops estimated to be within the survey area of 663 km^2, 34.9 million (53%, range 11–86% by area) were of a size at which they were likely to recruit to the fishery by the start of the season.

Table 8: **Summarised results of abundance surveys for scallops in the five major areas within the Northland fishery surveyed during 1998. Beds specified in the table relate to the following areas: "Spirits", Spirits Bay and Tom Bowling Bay; "Rangaunu", all beds between North Cape and Berghan Pt; "Cavalli", all beds between Berghan Pt and Cape Brett; "Bream Bay", Bream Bay only; "Mangawhai", all coastal beds between Bream Tail and Cape Rodney. The recruited population size is the estimated number of scallops 95 mm or greater shell length at the time of the survey, it being assumed that all such scallops will grow to 100 mm by the start of the season in July. Mean weight of recruits is estimated as the mean weight of all individuals 100 mm or greater shell length at the time of the survey**

Bed	Total population size ($*10^{-6}$)	Recruited population (>95mm)	Recruited density (m^{-2})	c.v. of recruited density	Mean recruit weight (g)	Approx. biomass (t)
Spirits	5.04	4.72	0.0489	0.16	128.7	608
Rangaunu	14.17	7.62	0.0254	0.16	111.8	852
Cavalli	2.57	1.39	0.0390	0.14	116.4	162
Bream Bay	2.60	0.18	0.0010	0.50	102.2	18
Mangawhai	2.19	<0.01	0.0001	1.01	93.4	<1
Total	26.58	13.92	0.0195	0.13	118.8	1 654

Growth rates

Growth rates in most Northland beds are not as well known as in the Coromandel fishery, but sufficient data from tag returns have now been accumulated to indicate that, as in the Coromandel fishery, scallops of about 95 mm in shell length at the time of surveys are likely to recruit to the fishery by the start of the season in July (Figure 23). Growth rates in Spirits Bay and Tom Bowling Bay are even less well known, but the few available data do not suggest a large difference from the rest of the Northland fishery.

Start of season recruited biomass

Using Equation (5) and assuming 6.47% mortality between survey and season (to allow for a 60 day lag), start of season recruited biomass for the Northland fishery can be estimated as:

$$13.92*10^6 * 118.83 * 0.9353 = 1547 \text{ t (greenweight), or}$$

$$\text{assuming 13.5\% recovery, } 1547 * 0.135 = 209 \text{ t (meatweight)}$$

These estimates both have a *c.v.* of 13.0% which includes variance associated with the estimate of mean dredge efficiency but not associated with estimates of growth rate, mortality rate, mean weight, or recovery fraction.

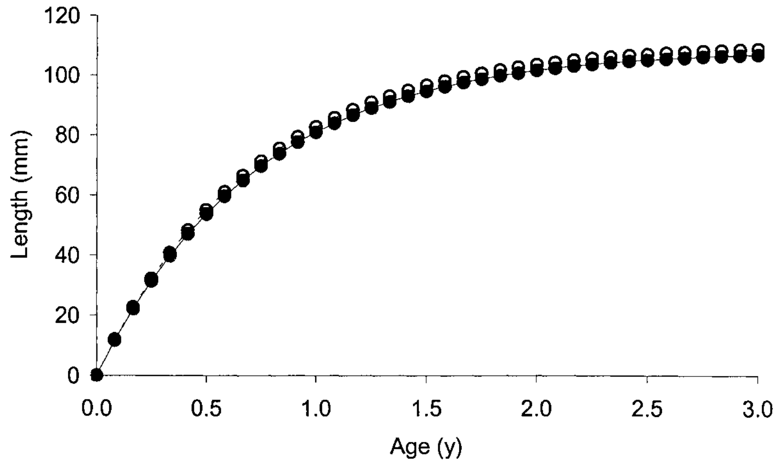

***Figure 23*: Average growth rates of scallops, as estimated using all data from each fishery in a GROTAG likelihood analysis, in the Coromandel (closed circles, solid line) and Northland (open circles, dotted line) fisheries (*see* also Table 3).**

The impact of Voluntary Closed Areas on start of season recruited biomass

Voluntary closed areas (VCAs) are in place in two areas in the Northland fishery (Appendix 6), off Spirits Bay (an initiative by fishers to protect unusual sponge-, hydroid- and bryozoan-dominated communities in the area) and in the Cavalli Passage (in consideration of the great amateur interest in this area).

The Spirits Bay closure covers about 14.3 km^2 (about 23% of the low density stratum 91), and contains about 470 000 scallops likely to grow to 100 mm by the start of the season (about 9.9% of the total for Spirits Bay and Tom Bowling Bay combined) for an aggregate weight of about 70 t. The average size of these scallops is very large (mean weight 149 g), but their estimated density is low (0.03 m^{-2}). Assuming 6.47% mortality between survey and season, the predicted start of season recruited biomass would be about 65 t (greenweight) lower if the scallops in the Spirits Bay VCA were to be excluded.

The Cavalli Passage closure is much smaller and overlaps sampling stratum 6 by 1.4 km^2 (15.5% of that stratum) and stratum 7 by 0.79 km^2 (16.2%). There are insufficient samples from either stratum to carry out a rigorous analysis of the density of scallops within the VCA, so it has been assumed that 15.5% and 16.2% of the scallops and biomass within these two strata (respectively) would be contained within the VCA. This amounts to about 135 000 scallops for an aggregate weight of 16 t (15.7% of the total for these two strata). Assuming 6.47% mortality between survey and season, the predicted start of season recruited biomass would be about 15 t (greenweight) lower if the scallops in the Cavalli Passage VCA were to be excluded.

The total abundance of scallops in the two VCAs in force in the Northland fishery is about 600 000 (about 4% of the total fishery by number) for a total recruited biomass of about 86 t (5% by weight). Were the biomass in the two VCAs to be excluded from the estimate of start of season recruited biomass for the fishery, the revised estimate would be 1467 t greenweight (1547 - 80 t) or, assuming 13.5% recovery, 198 t meatweight.

Discussion

Coromandel fishery

Scallop beds close to Whitianga have been surveyed by diver almost annually since 1980, but most other beds have been surveyed only in recent years (Table 9). Conditions at Whitianga are very similar to those in 1996 and 1997, following two very poor years in 1994 and 1995. Length frequency distributions for 1998 (*see* Figure 7) do, however, show larger numbers of pre-recruits than at any time since 1992, and this is encouraging for the future. The bed at Little Barrier Island appears to have declined significantly, in line with predictions from 1997 length frequency distributions that recruitment for the 1998 season was likely to be reduced. Length frequency distributions collected in 1998 suggest that this situation is not likely to improve in the near future, there being few pre-recruit animals compared with previous surveys. The population at Waiheke Island appears to have undergone a recovery since the very poor years of 1992–96. The *c.v.*s for the 1996 and 1997 surveys were both greater than 50% (which made the comparison a poor one in 1997), but that for 1998 is lower at 34% allowing more confidence in the improvement. Length frequency distributions from 1998 (*see* Figure 9) suggest continued high biomass in the short term (relative to the nadir in 1993–95). Most other beds (Waihi, Shoe, Slipper, Motiti, Papamoa, Colville) remain at low density and are not likely to contribute materially to the coming season's catch. The bed at Waihi, especially, is now at a very low ebb.

Overall, the survey suggests a total biomass of scallops (100 mm or greater length) very similar to that in 1997, and a slightly more robust population than was found in 1994–96. However, much of this improvement is attributable to the recovery of the Waiheke Island bed while there have been significant declines elsewhere. In the short term, this situation is likely to continue, large relatively dense populations at Whitianga and Waiheke Island are likely to be predominant.

***Table 9*: Number of scallops (millions, 95 mm or greater shell length) at the time of survey in constituent areas of the Coromandel fishery since 1990. Diver surveys at Whitianga were undertaken annually between 1978 and 1987, and dredge surveys were undertaken at Waiheke in 1984, 1985, and 1986. Dashes (–) indicate no survey**

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

Analysis of the length frequency distributions of scallops landed into processing sheds in Whitianga and Whangamata strongly suggests that there is heterogeneity in the selection behaviour of fishers within the Coromandel fishery. In 1997, it appears that some fishers were returning a large proportion of scallops of 90–94 mm to the water. Further, it appears (from consistently low selection of scallops in the range 90–92 mm) that up to about half of the fleet may have been practising such "highgrading", at least for scallops very close to the MLS of 90 mm. Landings from the three vessels with the lowest mean 5 percentile size had a length frequency distribution remarkably similar to that predicted from individual based modelling of the stock. In 1998, the prevalence of highgrading appeared to be lower and, indeed, towards the end of the season a trend towards landing a significant proportion of undersized scallops had developed.

It is not likely that differences in the proportion of scallops of 90–94 mm in the catch or the mean 5 percentile size are due to differences in the selectivity patterns of different dredges. The selectivity curves of scallop dredges examined as part of assessment work have all been so shallow as to be essentially flat over the range 90–95 mm. Conversely, selection by fishers can be almost knife edged, depending on the attention paid to careful measurement close to the MLS and on the handling of scallops after measurement (rough handling can lead to chipping and reduction in the measured size of some scallops).

Similarly, although differences in the (predicted) length frequency distribution of the available scallops seem to be correlated, as might be expected, with the observed length frequency distribution of landings, it is not likely that these differences can explain the differences in apparent selection behaviour between years. Most of the difference in apparent selection behaviour is in the 90–95 mm size range and, while the overall proportion of scallops of this size class in the population varies considerably, the relative proportions of scallops in each 1 mm class in the population remain quite constant. Thus, changes in apparent selection over about 5 mm in size are most likely a result of fisher behaviour.

Modelling of these stocks (Cryer & Morrison 1997) suggested that operating to a MLS greater than the legal MLS of 90 mm (selection against scallops of less than 95 mm or "high grading") is wasteful and likely to decrease long term productivity. If it is assumed that the observed patterns in the length frequency distribution of landings are caused largely by fisher behaviour, then there was a important change in such behaviour in 1998. Fewer fishers appeared to be high grading and, towards the end of the season, many were retaining scallops slightly smaller than the MLS of 90 mm. The most likely incentives for such behaviour are a concern for the long term productivity of the fishery (keeping fishing effort to a minimum) or a desire to improve poor catch rates. There is insufficient information to examine these alternatives in detail, although the different implications of the two are clear.

Northland fishery

The greatest uncertainty in the 1998 Northland assessment is introduced by the unknown average efficiency of the dredge used to do the survey. The estimated efficiency of the dredge in use, by comparison with divers in the Whangaroa stratum, was about 95%. If this efficiency were to be adopted as an estimate of the average efficiency across all grounds, then the biomass multiplier would be 1.05, and the start of season recruited biomass estimate would be only about 70% of that presented here (1054 t *vs.* 1547 t). Moreover, as the *c.v.* associated with the single estimate of dredge efficiency is quite wide (38%), the *c.v.* of the start of season biomass would increase concomitantly (from 13% to about 24%). This would have implications for yield estimation using current models (Cryer 1994, 1998a, 1998b).

There is no clear means by which to gauge which estimate of average dredge efficiency (and biomass multiplier) is the most appropriate for this survey. This introduces a large amount of intractable uncertainty into the assessment, and the implications for biomass and yield estimation are considerable.

Not all beds have been surveyed in all of the seven surveys of Northland scallops, so many comparisons are difficult. In particular, this is only the second survey to include Spirits and Tom Bowling Bays (previously in QMA 9, now part of the new QMA for Northland scallops) and the precision of the first survey was very poor, making comparisons difficult (Table 10).

The 1998 survey shows the lowest recorded abundance of recruiting scallops in most of the beds which support the Northland fishery south of North Cape (in FMA 1). Most beds hold fewer scallops likely to recruit to the fishery than in previous years. The greatest decline has been in Bream Bay where the 1998 recruited biomass is only 1% of that estimated in 1992. The possible recovery mooted in 1997 (Cryer & Parkinson 1997) appears not to have been real and was probably an artefact caused by the small number of samples taken in Bream Bay that year (at the request of fishers and MFish). The population estimate for the other important FMA 1 bed at Rangaunu Bay is also the lowest on record (excluding the dive survey of 1993 which did not cover the whole of the bed), and the distribution of scallops in this area has changed quite markedly from shallow to deep water since 1992.

Scallop populations west of North Cape have undoubtedly declined very markedly since the first survey in 1996. The abundance estimate for the Spirits and Tom Bowling Bay beds in 1998 is only about 20% of that recorded in 1996. The density of scallops within the favoured area off Spirits Bay (stratum 93) has declined even more markedly (by over 90%) from about 1.00 to about 0.07 m^{-2}.

Length frequency distributions do not seem to be as informative for the Northland fishery as they are for the Coromandel fishery. However, the length frequency distribution of scallops in Spirits Bay suggests that significant recruitment in this area may not have occurred since 1996 (*see* Figure 21). As the abundance of scallops declined markedly between 1996 and 1998, the lower tail of the length frequency distribution increased from less than 70 mm to more than 90 mm. In Rangaunu Bay, the relatively high abundance of pre-recruit scallops of 60–80 mm holds some promise for the future (*see* Figure 20), but elsewhere in the Northland fishery (*see* Figures 21 and 22) there are no strong signs of heavy recruitment which might lead to an improvement in the current state of the fishery.

***Table 10*: Number of scallops (millions, 95 mm or greater shell length) at the time of survey in constituent areas of the Northland fishery since surveys started in 1992. Surveys in 1993 were conducted entirely by dive and were missed substantial components of populations in Rangaunu Bay. The overall estimate of 9.9 million scallops in that year and 1.5 million in Rangaunu (*) are therefore likely to be substantially negatively biased. The stratum at Great Exhibition Bay in 1998 was about four times as large as previously (†). Estimates for 1998 are based on historical average dredge efficiency of 62% for all Northland survey vessels. The actual estimated efficiency for the 1998 survey vessel was 95% which would lead to abundance estimates about two thirds of those listed here. The total for Rangaunu Bay to Pakiri is included as the best comparison among years for beds surveyed consistently since 1992. Dashes (–) indicate no survey**

	1992	1993	1994	1995	1996	1997	1998
Spirits Bay	–	–	–	–	24.4	15.8	4.7
Gt Exhibition	–	–	–	1.1	0.9	1.0	†1.3
Rangaunu	7.0	*1.5	8.5	9.0	7.7	9.9	6.0
Doubtless	0.7	0.7	1.3	1.0	0.3	0.7	0.3
Whangaroa	–	1.7	0.6	2.3	1.2	1.1	0.5
Cavalli Passage	0.4	0.4	–	1.2	0.9	0.7	0.9
Bream Bay	16.8	5.5	4.2	3.5	2.2	5.7	0.2
Mangawhai	4.0	–	0.2	0.1	–	0.4	<<0.1
Rangaunu-Pakiri Total	28.9	*9.9	14.8	17.1	12.3	19.0	7.9
Overall Total	28.9	*9.9	14.8	18.2	37.6	34.9	13.9

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Appendix 1: **Stratum definitions, Coromandel scallop survey 1998**

Stratum	Location	Area (m^2)	Method
1	Whitianga (Sarah's Gully)	17 948 914	Dredge (sand)
2	Whitianga Shell Bank	8 649 902	Dredge (sand)
2.5	Whangapoua	8 953 125	Dredge (sand)
3	Whitianga Opito Bay	6 665 161	Dredge (sand)
3.5	Whitianga Opito deep	13 923 828	Dredge (sand)
4	Whitianga Mercury Cove	2 082 489	Dredge (mud)
7	Whitianga Bumper Cove	7 125 244	Dredge (sand)
8	Whitianga (3 Mile Bank)	12 580 322	Dredge (sand)
9	Whitianga Maori Lady	3 902771	Dredge (sand)
10	Waihi North	32 104 248	Dredge (sand)
11	Waihi South	24 854 980	Dredge (sand)
11.4	Shoe Island	1 086 163	Dredge (sand)
11.5	Slipper Island	12 797 455	Dredge (sand)
12	Motiti Northwest	10 338 013	Dredge (sand)
13	Motiti South	18 613 647	Dredge (sand)
14	Papamoa	60 677 368	Dredge (sand)
15	Motiti: "The Knoll"	6 828 622	Dredge (sand)
18	Barrier West	3 771 729	Dredge (sand)
19	Barrier South	4 795 044	Dredge (sand)
20	Waiheke Island Total	46 445 190	Dredge (mud)
31	Colville South, shallow	15 770 264	Dredge (mud)
32	Colville South, deep	19 845 215	Dredge (mud)
34	Colville North	1 409 119	Dredge (mud)

Appendix 2: **Stratum definitions, Northland scallop survey 1998**

Stratum	Location	Area (m^2)	Method
91	Spirits Bay Low density area	61 803 711	Dredge (sand)
93	Spirits Bay High density area	12 555 664	Dredge (sand)
92	Tom Bowling Bay	22 097 656	Dredge (sand)
1	Great Exhibition Bay	64 118 164	Dredge (sand)
2	Rangaunu Bay Inner	111 593 750	Dredge (sand)
2.1	Rangaunu Bay Outer	72 287 109	Dredge (sand)
3	Doubtless Bay	52 852 051	Dredge (sand)
5	Whangaroa Bay	12 347 656	Dredge (sand)
5.5	Flat Island	3 609 375	Dredge (sand)
6	Cavalli Passage	9 063 660	Dredge (sand)
7	Matauri Bay	4 860 840	Dredge (sand)
7.5	Takou Bay	5 853 668	Dredge (sand)
8	Bream Bay Inner	102 698 242	Dredge (sand)
8.1	Bream Bay Outer	73 662 109	Dredge (sand)
9	Mangawhai	36 454 590	Dredge (sand)
10	Pakiri North	42 457 031	Dredge (sand)
11	Pakiri South	25 343 262	Dredge (sand)

***Appendix 3*: A review of the performance of the optimisation procedure used for scallop surveys between 1990 and 1997**

General

Surveys for northern scallops have historically been optimised by using the density of scallops unlikely to recruit by the start of the season as a predictor of the density and variance of recruited scallops in the following year. This approach was adopted to take into account the temporal and spatial variability in scallop density, but its performance has not hitherto been tested.

Methods

For scallop surveys between 1990 and 1997, stations were allocated to strata based on the following equation:

$$n_i = N \,.\, A_i V_i / \Sigma A_i V_i$$

where N is the total number of sites in the sampling phase, n_i is the number of samples allocated to stratum i of area A_i and variability V_i (Sukhatme & Sukhatme 1970). The mean density of scallops under 95 mm shell length within each stratum in the previous year's survey was used as a surrogate for variability, V_i. (The mean and standard deviation are often correlated in patchy distributions and more robust to outliers than the standard deviation. A minimum allocation of about four shots per stratum has generally been applied).

To examine the performance of this procedure and some alternative procedures, the V_i in the above equation were substituted with the following quantities.

1. The mean density of scallops under 95 mm in year (t-1) (the current optimisation method).
2. The standard deviation of the density of scallops under 95 mm in year (t-1).
3. The mean density of scallops under 85 mm in year (t-1).
4. The standard deviation of the density of scallops under 85 mm in year (t-1).
5. The historical average density of scallops 95 mm or greater (1992–96).
6. The historical standard deviation of scallops 95 mm or greater (1992–96).
7. A constant (station allocation according to stratum area alone).
8. The actual standard deviation (in hindsight) of the density of scallops 95 mm or greater for the survey being optimised (a "perfect" survey).

For the purpose of this exercise, all historical data were analysed from scratch using identical methods and identical dredge efficiency and selectivity parameters (being the composite curve developed by Cryer & Parkinson (1997)). Hypothetical surveys were then designed for 1996 and 1997 assessments in the Northland and Coromandel fisheries using the seven methods described above. For each of the seven methods, the minimum allocation of shots to strata was varied from three to the maximum possible (being an equal division of shots among the strata). This essentially leads to a ninth possible design, towards which the other designs tend as the minimum allocation of shots to strata is increased.

For each survey design, a predicted survey *c.v.* was calculated using the stratum areas, the actual estimates of the standard deviation of scallop counts (95 mm or more shell length) from the real survey, and the number of shots from the optimisation.

Following an examination of the performance of the optimisation methods, some methods of combining the various methods to minimise the chance of generating extreme survey designs were examined.

Results

The designs and predicted *c.v.*s are tabulated for a minimum allocation of four shots per stratum (Tables A3.1–A3.4), and plotted graphically over the whole possible range of possible minimum allocations in Figures A3.1 (for 1996 surveys) and A3.2 (for 1997 surveys)

None of the optimisation methods adopted here consistently generated the "best" survey design for the four surveys tested. Surveying in accordance with (recent) historical average density generated the most precise surveys in three out of four surveys, but by far the least precise in the fourth (Coromandel, 1997). Similarly, surveying in accordance with predicted scallop abundance (or its variability) led to very precise surveys in some surveys (Coromandel 1997), but this approach had success which was variable between fisheries (better in Coromandel than in Northland) and with the size class used to predict scallop abundance (less than 95 mm shell length performed better than less than 85 mm in Northland, despite the likely high growth rates in that fishery).

The current method of allocating shots in accordance with the mean density of pre-recruit scallops and the size of each stratum is consistently more efficient than using the estimated standard deviation. The difference in some surveys is small (Northland, 1997), but in others it is quite large (Northland and Coromandel, 1996). The greater efficiency of optimising using area and mean density (as opposed to its standard deviation) may be because the mean density can be estimated more precisely using fewer samples than can its standard deviation.

The allocation of shots to strata based simply on stratum area performed surprisingly well in some surveys (Coromandel, 1997), but poorly in others (Coromandel, 1996). This probably reflects changes in the relative density (and hence variability) of scallops among strata, with a relatively homogeneous distribution of scallops in the years when this method worked well, and more heterogeneous distribution in years when it did not.

Small minimum allocations of stations to strata (the absolute minimum being two for a stratified random survey) sometimes lead to wide differences between predicted survey *c.v.*s from different optimisation methods. The extreme case is the 1997 Coromandel survey where the worst predicted *c.v.* (based on historical scallop density) was almost 30% and the best (based on the mean density of scallops under 85 mm in the previous year) was about 11%, very close to the theoretical minimum for that number of stations and strata. As the minimum allocation is increased, the predicted survey *c.v.*s for the several methods converge to the *c.v.* which would be generated by an equal allocation of stations to strata.

Using two or more optimisation methods and "averaging" the resultant survey designs seemed to offer some benefits in minimising the chances of generating extreme designs and reducing the impact of poor estimates of stratum density or variance in the year before the survey. The best and most consistent of these methods was to generate survey designs using methods 3, 4, 5, and 6 (Coromandel) or 1, 2, 5, and 6 (Northland), and to average the shot allocations from the four designs for each stratum. This composite optimisation procedure appeared to be more robust and a more consistent and accurate predictor of survey performance than any of the individual methods. The composite method takes into account the historical average performance of each stratum as well as the (estimated) variability of scallop density in the preceding year and the size of the stratum.

Discussion

The standard deviations of scallop counts used do not include variance associated with the estimate of dredge efficiency as this would be constant among years for this analysis (where the same dredge efficiency curve is used for all years). This means that the survey *c.v.*s generated in this analysis are optimistic. Conversely, the survey designs are single phase and, in practice, at least some stations can usually be included in a second phase to revisit strata of high variability and this normally (not always) leads to lower *c.v.*s. Both these factors can be considered to be consistent among years, though, and the predicted survey *c.v.*s generated here should be comparable for this analysis.

Using small minimum allocations of stations to strata appears to be a risky approach for scallop surveys. Small minimum allocations lead to very precise survey *c.v.*s if the optimisation process is accurate and scallop distribution is close to predicted, but there is a chance of generating a very poor survey if scallop distribution is not as predicted. These "poor" surveys are rapidly improved by greater minimum allocations, while there appears to be very little degradation of "good" surveys by minimum allocations of five shots or less. Clearly, a formal second phase or the flexibility to include some additional shots when unexpectedly high variability is encountered can also dramatically improve the performance of a poor survey.

Conclusions

None of the optimisation processes used here consistently outperformed the others. This is probably a result of the different circumstances surrounding each of the four surveys and the variable nature of scallop distribution and abundance. However, when allied with a minimum allocation of four or five stations, methods based on the predicted abundance or variability from the previous year's survey seem to be quite reliable.

The mean density by stratum should be used rather than its standard deviation, and a size range of less than 95 mm appears better for the Northland fishery as opposed to less than 85 mm in the Coromandel fishery. Where previous survey data are not available (as in new strata), then allocation on the basis of area alone seems to be sensible.

A composite optimisation procedure using historical average performance as well as information from the immediately preceding year performed best of all the methods examined and, perhaps after some further analysis of its performance on 1995 and 1998 surveys, it could be adopted for the future.

Whatever the optimisation process used, there remains a chance of a survey being poorly matched with scallop distribution and variability in any given year. Some flexibility to include additional (random) shots during the survey, or for a formal second phase, will help to improve precision in these instances.

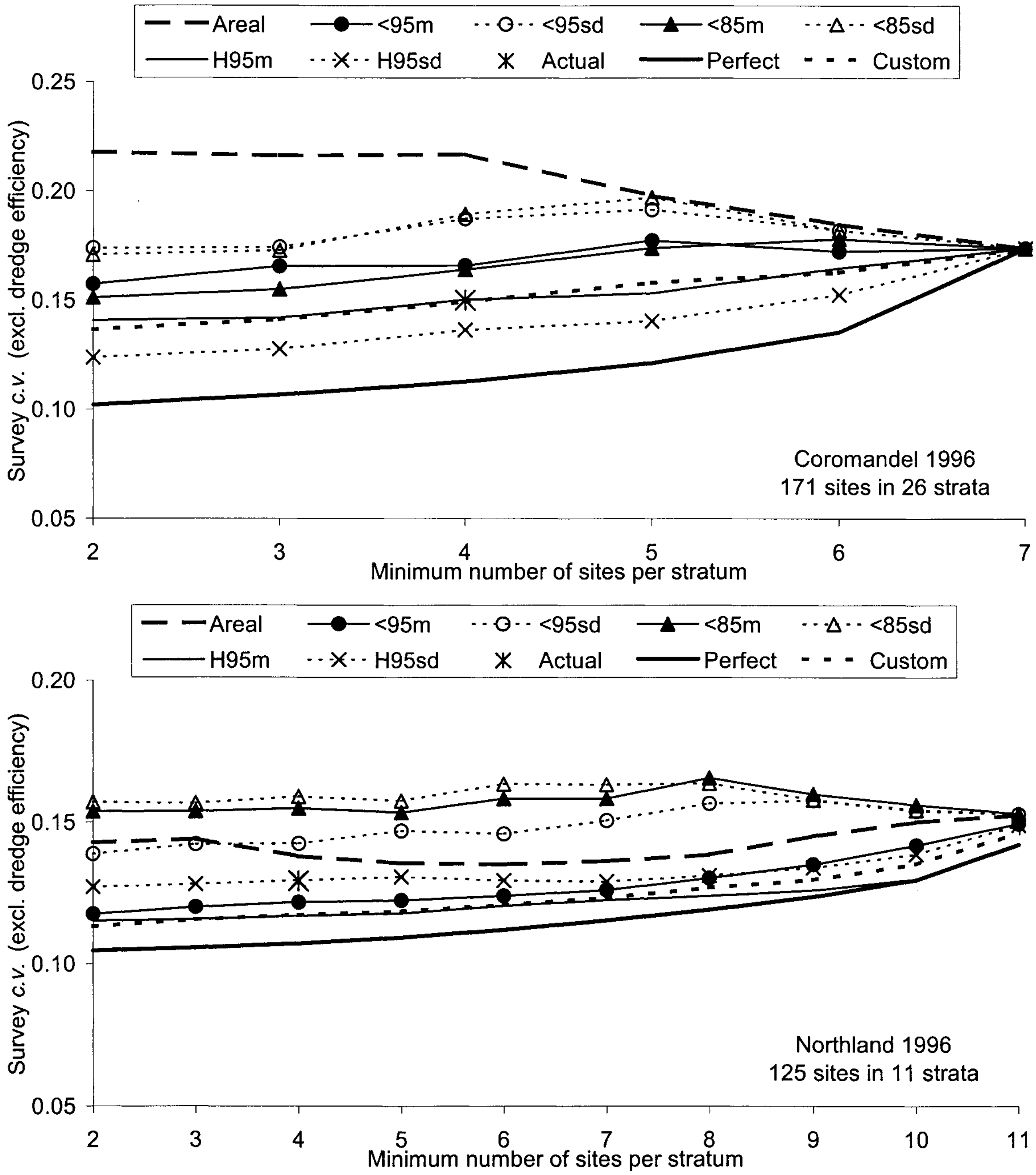
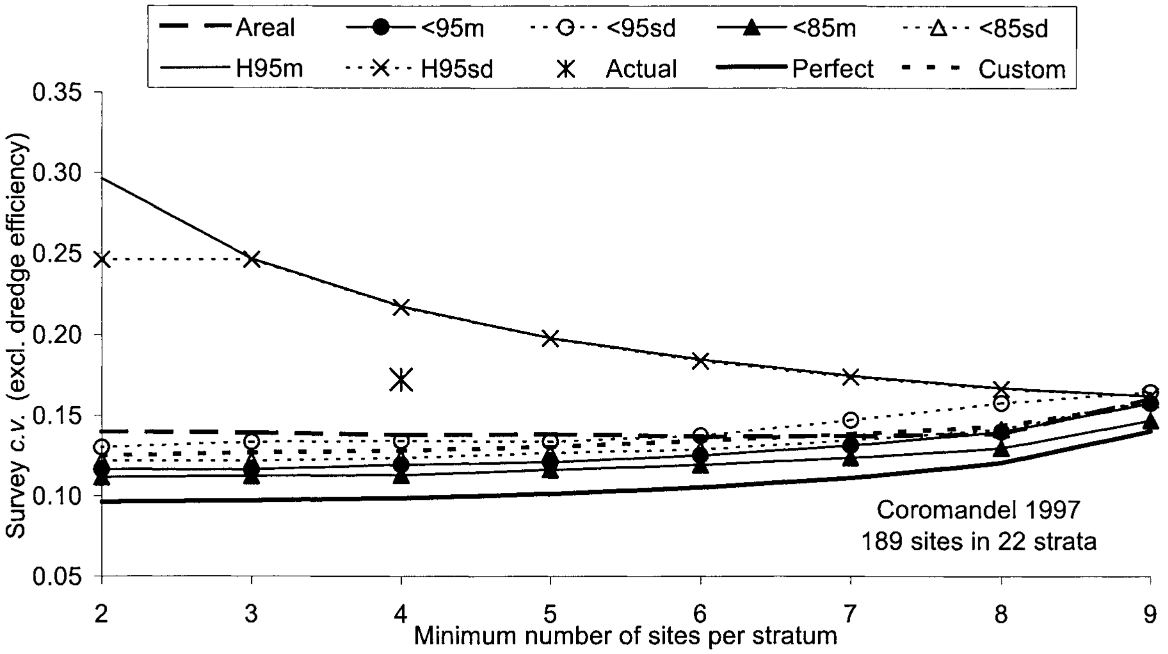


***Figure A3.1*: Predicted survey *c.v.s* for simulated 1996 surveys in the Coromandel (top) and Northland (bottom) scallop surveys based on several optimisation methods. The large cross represents the actual 1996 survey *c.v.s* and the "perfect" line represents the best *c.v.* possible with prior knowledge of scallop variability by stratum. The "custom" line shows the results of a composite optimisation based partly on predictions from the 1995 survey and partly on historical performance. Other lines relate to optimisation methods based on the mean and standard deviation of the density of scallops less than 85 or 95 mm shell length in 1995, on the average (5 year historical) mean density of scallops 95 mm or greater shell length and its standard deviation, and simply on the area of each stratum.**



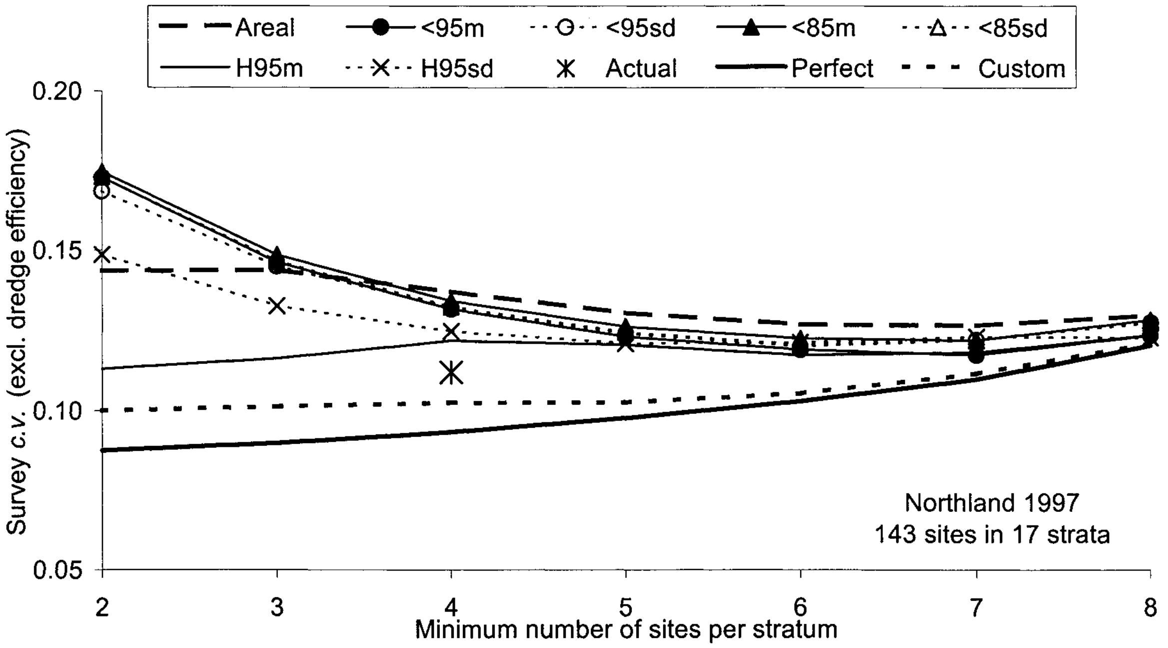


***Figure A3.2*: Predicted survey *c.v.*s for simulated 1997 surveys in the Coromandel (top) and Northland (bottom) scallop surveys based on several optimisation methods. The black dots represents the actual 1997 survey *c.v.*s and the "perfect" line represents the best *c.v.* possible with prior knowledge of scallop variability by stratum. The "custom" line shows the results of a composite optimisation based partly on predictions from the 1996 survey and partly on historical performance. Other lines relate to optimisation methods based on the mean and standard deviation of the density of scallops less than 85 or 95 mm shell length in 1996, on the average (5 year historical) mean density of scallops 95 mm or greater shell length and its standard deviation, and simply on the area of each stratum.**

Table A3.1: **Area, mean, and standard deviation by stratum of the density of scallops larger than 95 mm in the 1996 Coromandel survey, and the predicted performance of eight methods of allocating stations to strata. “Areal”, stations in proportion to stratum area; “< 95m” and “< 95sd”, allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops smaller than 95 mm in 1995 (similarly for “< 85m” and “< 85sd”); “H95m” and “H95sd”, allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops larger than 95 mm in the previous 5 years; Custom”, the mean of predictions “< 95m”, “< 95sd”, “H95m”, and “H95sd”; “Actual”, the survey conducted in 1996; “Perfect”, an hypothetical survey based on perfect prior knowledge**

Stratum	Area (m^2)	Mean 1996	SD 1996	Areal	< 95m	< 95sd	< 85m	< 85sd	H95m	H95sd	Custom	Actual	Perfect
1	17 948 914	0.0440	0.0404	9	9	13	9	10	7	8	9	7	4
2	8 649 902	0.0786	0.1048	4	15	19	20	24	5	7	14	16	5
3	5 727 905	0.0676	0.0483	4	7	4	8	4	6	7	6	4	4
3.1	299 072	0.1488	0.1012	4	4	4	4	4	4	4	4	4	4
3.2	315 186	0.1652	0.0942	4	4	4	4	4	4	4	4	4	4
3.3	322 876	0.1853	0.1471	4	4	4	4	4	4	4	4	4	4
4	2 062 489	0.0749	0.0593	4	4	4	4	4	4	4	4	4	4
7	7 125 244	0.3963	0.6999	4	6	5	7	6	7	10	8	8	28
8	12 580 322	0.1428	0.1846	6	5	5	5	5	10	10	8	14	13
9	2 469 177	0.0634	0.0542	4	4	4	4	4	4	4	4	6	4
10	32 104 248	0.0054	0.0031	16	4	4	4	4	10	7	6	6	4
11	24 854 980	0.0051	0.0036	12	4	4	4	4	8	8	6	6	4
12	12 973 755	0.0786	0.0810	7	7	6	4	4	9	8	6	13	6
13	21 014 404	0.0466	0.0669	11	18	19	17	20	12	13	16	14	8
14	25 973 267	0.0545	0.0707	13	22	24	22	25	10	12	17	7	10
18	2 449 829	0.6774	0.4466	4	4	4	4	4	12	7	7	6	6
19	7 492 310	0.4374	0.5452	4	14	7	11	5	19	18	13	12	23
21	23 405 470	0.0098	0.0196	12	4	4	4	4	4	4	4	4	4
22	4 110 352	0.0044	0.0074	4	4	4	4	4	4	4	4	4	4
23	5 166 137	0.0239	0.0404	4	4	4	4	4	4	4	4	4	4
24	10 660 189	0.0000	0.0000	5	4	4	4	4	4	4	4	4	4
26	3 102 295	0.0056	0.0093	4	4	4	4	4	4	4	4	4	4
28	28 212 891	0.0041	0.0082	14	4	4	4	4	4	4	4	4	4
31	9 193 350	0.0170	0.0235	5	4	4	4	4	4	4	4	4	4
32	10 025 391	0.0020	0.0015	5	4	4	4	4	4	4	4	4	4
34	1 409 119	0.0292	0.0255	4	4	4	4	4	4	4	4	4	4
Total		0.0584		171	171	170	171	171	171	171	172	171	171
Survey *c.v.*:				0.217	0.166	0.187	0.164	0.189	0.150	0.137	0.149	0.150	0.113

***Table A3.2*: Area, mean, and standard deviation by stratum of the density of scallops larger than 95 mm in the 1996 Northland survey, and the predicted performance of eight methods of allocating stations to strata. “Areal”, stations in proportion to stratum area; “< 95m” and “< 95sd”, allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops smaller than 95 mm in 1995 (similarly for “< 85m” and “< 85sd”); “H95m” and “H95sd”, allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops larger than 95 mm in the previous 5 years; Custom”, the mean of predictions “< 95m”, “< 95sd”, “H95m”, and “H95sd”; “Actual”, the survey conducted in 1996; “Perfect”, an hypothetical survey based on perfect prior knowledge**

Stratum	Area (m^2)	Mean 1996	SD 1996	Areal	< 95m	< 95sd	< 85m	< 85sd	H95m	H95sd	Custom	Actual	Perfect
1	13 209 717	0.0872	0.0340	4	8	6	6	6	8	4	7	5	4
2	111 593 750	0.0135	0.0233	29	14	26	16	23	16	29	21	26	18
2.1	72 287 109	0.1160	0.0764	18	24	12	10	9	36	24	24	16	39
3	36 527 832	0.0075	0.0183	9	4	5	9	10	5	8	6	6	5
4	16 682 617	0.0008	0.0020	4	4	4	4	4	15	16	10	6	4
5	12 347 656	0.1268	0.1788	4	27	32	32	29	9	5	18	12	16
5.5	3 609 375	0.1051	0.0478	4	4	4	4	4	4	4	4	4	4
6	9 063 660	0.0571	0.0419	4	4	4	4	4	4	4	4	5	4
7	4 860 840	0.0482	0.0327	4	4	4	4	4	4	4	4	6	4
8	102 698 242	0.0132	0.0213	26	26	23	32	28	16	18	21	30	16
8.1	73 662 109	0.0144	0.0219	19	5	5	4	4	8	9	7	9	11
Total		0.0360		125	124	125	125	125	125	125	126	125	125
Survey *c.v.*:				0.138	0.122	0.142	0.155	0.159	0.117	0.130	0.117	0.129	0.107

***Table A3.3*:** **Area, mean, and standard deviation by stratum of the density of scallops larger than 95 mm in the 1997 Coromandel survey, and the predicted performance of eight methods of allocating stations to strata. “Areal”, stations in proportion to stratum area; “< 95m” and “< 95sd”, allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops smaller than 95 mm in 1995 (similarly for “< 85m” and “< 85sd”); “H95m” and “H95sd”, allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops larger than 95 mm in the previous 5 years; Custom”, the mean of predictions “< 95m”, “< 95sd”, “H95m”, and “H95sd”; “Actual”, the survey conducted in 1996; “Perfect”, an hypothetical survey based on perfect prior knowledge**

Stratum	Area (m^2)	Mean 1997	SD 1997	Areal	< 95m	< 95sd	< 85m	< 85sd	H95m	H95sd	Custom	Actual	Perfect
1	17 948 914	0.0602	0.1053	12	7	4	7	5	9	11	8	20	13
2	8 649 902	0.0761	0.0825	6	18	24	13	20	7	9	12	14	5
3	5 727 905	0.0707	0.0846	4	9	8	11	11	8	9	10	8	4
3.1	299 194	0.1160	0.1470	4	4	4	4	4	4	4	4	4	4
3.2	315 186	0.0062	0.0094	4	4	4	4	4	4	4	4	4	4
3.3	322 876	0.1302	0.0447	4	3	3	3	3	3	3	3	3	3
4	2 082 489	0.2825	0.1777	4	4	4	4	4	4	4	4	6	4
7	7 125 244	0.0874	0.1902	5	27	36	28	37	10	14	22	20	9
8	12 580 322	0.1826	0.2340	8	14	12	11	11	13	14	12	11	20
9	2 469 177	0.1368	0.1786	4	4	4	4	4	4	4	4	7	4
10	32 104 248	0.0131	0.0136	21	4	4	4	4	14	9	8	7	4
11	24 854 980	0.0121	0.0113	16	4	4	4	4	10	11	7	7	4
12	10 338 013	0.0422	0.0859	7	5	4	4	4	9	8	6	5	6
13	18 613 647	0.0407	0.0301	12	4	5	4	5	14	15	10	5	4
14	25 973 267	0.0048	0.0094	17	6	5	4	4	13	16	9	9	4
15	6 828 622	0.0862	0.0800	4	4	4	4	4	6	5	5	5	4
18	2 449 829	0.5466	0.4971	4	5	4	5	4	16	9	9	10	8
19	7 492 310	0.3587	0.4251	5	28	26	25	19	25	24	23	22	22
20	46 445 190	0.1143	0.1598	31	23	18	34	26	4	4	17	7	51
31	8 463 867	0.0049	0.0043	6	4	4	4	4	4	4	4	3	4
32	10 755 859	0.0130	0.0226	7	4	4	4	4	4	4	4	5	4
34	1 409 119	0.0994	0.0984	4	4	4	4	4	4	4	4	7	4
Total		0.0725		189	189	189	189	189	189	189	189	189	189
Survey *c.v.*:				0.138	0.119	0.134	0.113	0.124	0.217	0.217	0.128	0.172	0.099

***Table A3.4*: Area, mean, and standard deviation by stratum of the density of scallops larger than 95 mm in the 1997 Northland survey, and the predicted performance of eight methods of allocating stations to strata. "Areal", stations in proportion to stratum area; "< 95m" and "< 95sd", allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops smaller than 95 mm in 1995 (similarly for "< 85m" and "< 85sd"); "H95m" and "H95sd", allocation in proportion to the product of area and the mean (standard deviation) of the density of scallops larger than 95 mm in the previous 5 years; Custom", the mean of predictions "< 95m", "< 95sd", "H95m", and "H95sd"; "Actual", the survey conducted in 1996; "Perfect", an hypothetical survey based on perfect prior knowledge**

Stratum	Area (m^2)	Mean 1997	SD 1997	Areal	< 95m	< 95sd	< 85m	< 85sd	H95m	H95sd	Custom	Actual	Perfect
1	13 209 717	0.0546	0.0308	4	4	4	4	4	4	4	4	6	4
2	111 593 750	0.0137	0.0216	22	4	4	4	4	5	16	7	14	8
2.1	72 287 109	0.1125	0.0622	14	21	24	16	21	12	13	18	14	15
3	52 852 501	0.0088	0.0100	10	4	4	4	4	4	6	5	5	4
5	12 347 656	0.0929	0.1990	4	4	4	4	4	4	6	5	14	8
5.5	3 609 375	0.0516	0.0350	4	4	4	4	4	4	4	4	6	4
6	9 063 660	0.0090	0.0096	4	4	4	4	4	4	4	4	5	4
7	4 860 840	0.0617	0.1298	4	4	4	4	4	4	4	4	5	4
7.5	5 853 668	0.0020	0.0027	4	4	4	4	4	4	4	4	5	4
8	102 698 242	0.0487	0.0553	20	28	42	32	45	5	10	21	6	19
8.1	73 662 109	0.0078	0.0091	15	12	8	10	6	4	5	7	6	4
9	36 454 590	0.0075	0.0079	7	14	6	19	8	4	4	7	4	4
10	42 457 031	0.0008	0.0010	8	4	4	4	4	4	4	4	4	4
11	25 343 262	0.0020	0.0025	5	5	4	7	4	4	4	4	4	4
91	61 803 711	0.1135	0.1204	12	21	17	17	17	30	45	28	20	24
92	22 097 656	0.1651	0.1720	4	4	4	4	4	4	8	5	7	12
93	12 555 664	0.4062	0.4710	4	4	4	4	4	45	4	14	18	19
Total		0.0517		145	145	145	145	145	145	145	145	143	145
Survey *c.v.*:				0.137	0.132	0.132	0.134	0.132	0.122	0.125	0.103	0.112	0.093

***Appendix 4a*: Analysis of the impact of Voluntary Closed Areas on the estimation of scallop abundance and biomass at 100 mm shell length and above: proposals from commercial fishers. The percentage of surveyed area and the estimated percentage of scallops in this size class are given at the bottom of the table**

Stratum description	Code	Area (ha)	% in VCA	VCA name	VCA area	Area lost	Total scallops	Revised total	Scallops lost
Sarah's Gully	1	17.949	4.9	Blackjacks	1.23	0.88	714 000	720 000	0
Blackjacks	2	8.649	0	–	–	0	488 000	488 000	0
Whangapoua	2.5	8.953	0	–	–	0	210 000	210 000	0
Opito inner	3	6.665	5.5	Opito	0.93	0.37	978 000	924 210	53 790
Opito outer	3.5	13.924	0	–	–	0	1 908 000	1 908 000	0
Mercury Cove	4	2.082	1.6	Mercury Cove }	–	0	697 000	685 848	11 152
Mercury Cove deep	8	12.580	0	Mercury Cove }	1.19	0.03	1 067 000	1 067 000	0
Bumper Cove	7	7.125	0	Bumper Cove	–	0	109 000	109 000	0
Whitianga islands	9	3.903	0	–	–	0	265 000	265 000	0
Waihi North	10	32.104	0	–	–	0	42 000	42 000	0
Waihi South	11	24.85	12.6	Waihi Beach	49.9	3.13	65 000	50 000	15 000
Shoe	11.4	1.086	100.0	Shoe / Slipper }	–	1.09	15 000	0	15 000
Slipper	11.5	12.797	16.7	Shoe / Slipper }	48.1	2.14	84 000	87 000	0
Motiti West	12	10.338	26.0	Motiti }	14.3	2.69	587 000	528 594	58 407
Motiti - the Knoll	15	6.829	0	Motiti }	–	0	425 000	425 000	0
Motiti South	13	18.614	0	–	–	0	70 000	70 000	0
Papamoa	14	60.677	0	Papamoa	–	0	81 000	81 000	0
Little Barrier West	18	3.772	0	–	–	0	614 000	614 000	0
Little Barrier South	19	4.795	0	–	–	0	342 000	342 000	0
Waiheke	20	46.445	0.5	Waiheke	2.74	0.25	5 246 000	5 217 672	28 328
Colville inner	31	15.770	0	–	–	0	95 000	95 000	0
Colville outer	32	19.845	0	–	–	0	7 000	7 000	0
Colville North	34	1.409	0	–	–	0	98 000	98 000	0
Total		341.168	–	–	118.33	10.57 (3.1%)	14 207 000	14034323.1	181 677 (1.3%)

***Appendix 4b*: Analysis of the impact of Voluntary Closed Areas on the estimation of scallop abundance and biomass at 100 mm shell length and above: proposals from recreational fishers. The percentage of surveyed area and the estimated percentage of scallops in this size class are given at the bottom of the table**

Stratum description	Code	Stratum area	% in VCA	VCA name	VCA area	Area lost	Total scallops	Revised total	Scallops lost
Sarah's Gully	1	17.949	4.9	Blackjacks	1.23	0.88	714 000	720 000	0
Blackjacks	2	8.649	0	–	–	0	488 000	488 000	0
Whangapoua	2.5	8.953	0	–	–	0	210 000	210 000	0
Opito inner	3	6.665	19.2	Opito	2.39	1.28	978 000	791 000	187 000
Opito outer	3.5	13.924	0	–	–	0	1 908 000	1 908 000	0
Mercury Cove	4	2.082	60.3	Mercury Cove }	–	1.26	697 000	290 000	407 000
Mercury Cove deep	8	12.580	5.4	Mercury Cove }	3.98	0.68	1 067 000	1 009 000	58 000
Bumper Cove	7	7.125	1.9	Bumper Cove	0.58	0.14	109 000	107 000	2 000
Whitianga islands	9	3.903	0	–	–	0	265 000	265 000	0
Waihi North	10	32.104	0	–	–	0	42 000	42 000	0
Waihi South	11	24.85	12.6	Waihi Beach	49.88	3.13	65 000	50 000	15 000
Shoe	11.4	1.086	100.0	Shoe / Slipper }	–	1.09	15 000	0	15 000
Slipper	11.5	12.797	16.7	Shoe / Slipper }	48.11	2.14	84 000	87 000	0
Motiti West	12	10.338	60.0	Motiti }	–	6.20	587 000	78 000	509 000
Motiti - the Knoll	15	6.829	98.0	Motiti }	38.62	6.69	425 000	0	425 000
Motiti South	13	18.614	0	–	–	0	70 000	70 000	0
Papamoa	14	60.677	26.0	Papamoa	57.18	15.78	81 000	84 000	0
Little Barrier West	18	3.772	0	–	–	0	614 000	614 000	0
Little Barrier South	19	4.795	0	–	–	0	342 000	342 000	0
Waiheke	20	46.445	24.0	Waiheke	16.18	11.15	5 246 000	3 516 000	1 730 000
Colville inner	31	15.770	0	–	–	0	95 000	95 000	0
Colville outer	32	19.845	0	–	–	0	7 000	7 000	0
Colville North	34	1.409	0	–	–	0	98 000	98 000	0
Total		341.168	–	–	218.16	50.40 (14.8%)	14 207 000	10 871 000	3 348 000 (23.6%)

Appendix 5a: **Analysis of the impact of Voluntary Closed Areas on the estimation of scallop abundance and biomass at 90 mm shell length and above: proposals from commercial fishers. The percentage of surveyed area and the estimated percentage of scallops in this size class are given at the bottom of the table**

Stratum description	Code	Stratum area	% in VCA	VCA name	VCA area	Area lost	Total scallops	Revised total	Scallops lost
Sarah's Gully	1	17.949	4.9	Blackjacks	1.23	0.88	1 363 478	1 421 233	0
Blackjacks	2	8.649	0	–	–	0	1 260 227	1 260 227	0
Whangapoua	2.5	8.953	0	–	–	0	247 405	247 405	0
Opito inner	3	6.665	5.5	Opito	0.93	0.37	3 055 573	2 887 516	168 056
Opito outer	3.5	13.924	0	–	–	0	5 504 909	5 504 909	0
Mercury Cove	4	2.082	1.6	Mercury Cove }	1.19	0.03	1 352 043	1 330 410	21 633
Mercury Cove deep	8	12.580	0	Mercury Cove }	–	0	2 672 968	2 672 968	0
Bumper Cove	7	7.125	0	Bumper Cove	–	0	310 767	304 862	5 905
Whitianga islands	9	3.903	0	–	–	0	844 775	844 775	0
Waihi North	10	32.104	0	–	–	0	42 245	42 245	0
Waihi South	11	24.85	12.6	Waihi Beach	49.88	3.13	65 412	50 024	15 388
Shoe	11.4	1.086	100.0	Shoe / Slipper }	–	1.09	17 362	0	17 362
Slipper	11.5	12.797	16.7	Shoe / Slipper }	48.11	2.14	90 355	94 083	0
Motiti West	12	10.338	26.0	Motiti }	14.25	2.69	734 591	661 499	73 092
Motiti - the Knoll	15	6.829	0	Motiti }	–	0	595 297	595 297	0
Motiti South	13	18.614	0	–	–	0	87 476	87 476	0
Papamoa	14	60.677	0	Papamoa	–	0	81 473	81 473	0
Little Barrier West	18	3.772	0	–	–	0	773 761	773 761	0
Little Barrier South	19	4.795	0	–	–	0	745 560	745 560	0
Waiheke	20	46.445	0.5	Waiheke	2.74	0.25	14 543 561	14 465 026	78 535
Colville inner	31	15.770	0	–	–	0	40 453	40 453	0
Colville outer	32	19.845	0	–	–	0	342 287	342 287	0
Colville North	34	1.409	0	–	–	0	407 882	407 882	0
Total		341.168			118.33	10.57 (3.1%)	35 179 859	34 861 371	379 971 (1.1%)

Appendix 5b: **Analysis of the impact of Voluntary Closed Areas on the estimation of scallop abundance and biomass at 90 mm shell length and above: proposals from recreational fishers. The percentage of surveyed area and the estimated percentage of scallops in this size class are given at the bottom of the table**

Stratum description	Code	Stratum area	% in VCA	VCA name	VCA area	Area lost	Total scallops	Revised total	Scallops lost
Sarah's Gully	1	17.949	4.9	Blackjacks	1.23	0.88	1 363 478	1 421 233	0
Blackjacks	2	8.650	0	–	–	0	1 260 227	1 260 227	0
Whangapoua	2.5	8.953	0	–	–	0	247 405	247 405	0
Opito inner	3	6.665	19.2	Opito	2.39	1.28	3 055 573	2 468 903	586 670
Opito outer	3.5	13.924	0	–	–	0	5 504 909	5 504 909	0
Mercury Cove	4	2.082	60.3	Mercury Cove }	–	1.26	1 352 043	608 395	743 647
Mercury Cove deep	8	12.580	5.4	Mercury Cove }	3.98	0.68	2 672 968	2 528 628	144 340
Bumper Cove	7	7.125	1.9	Bumper Cove	0.58	0.14	310 767	304 862	5 905
Whitianga islands	9	3.903	0	–	–	0	844 775	844 775	0
Waihi North	10	32.104	0	–	–	0	42 245	42 245	0
Waihi South	11	24.855	12.6	Waihi Beach	49.88	3.13	65 412	50 024	15 388
Shoe	11.4	1.086	100.0	Shoe / Slipper }	–	1.09	17 362	0	17 362
Slipper	11.5	12.797	16.7	Shoe / Slipper }	48.11	2.14	90 355	94 083	0
Motiti West	12	10.338	60.0	Motiti }	–	6.20	734 591	85 508	649 083
Motiti - the Knoll	15	6.829	98.0	Motiti }	38.62	6.69	595 297	0	595 297
Motiti South	13	18.614	0	–	–	0	87 476	87 476	0
Papamoa	14	60.677	26.0	Papamoa	57.18	15.78	81 473	84 406	0
Little Barrier West	18	3.772	0	–	–	0	773 761	773 761	0
Little Barrier South	19	4.795	0	–	–	0	745 560	745 560	0
Waiheke	20	46.445	24.0	Waiheke	16.18	11.15	14 543 561	11 055 876	3 487 685
Colville inner	31	15.770	0	–	–	0	40 453	40 453	0
Colville outer	32	19.845	0	–	–	0	342 287	342 287	0
Colville North	34	1.409	0	–	–	0	407 882	407 882	0
Total		341.169			218.16	50.40	35 179 859	28 998 898	6 245 377
						14.8%			17.8%