Biomass survey and stock assessment for the Coromandel scallop fishery, 2009

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New Zealand Fisheries Assessment Report 2010/33
October 2010

Published by Ministry of Fisheries
Wellington
2010

ISSN 1175-1584 (print)
ISSN 1179-5352 (online)

Williams, J.R.; Parkinson, D.M.; Tuck, I.D. (2010).
Biomass survey and stock assessment for the Coromandel scallop fishery, 2009.
.New Zealand Fisheries Assessment Report 2010/33.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

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New Zealand Fisheries Assessment Report 2010/33.

A dredge survey for scallops was carried out in the Coromandel scallop fishery in May 2009, with a total of 118 valid stations (dredge tows) sampled. Absolute start-of-season recruited biomass (scallops over 90 mm shell length, the commercial minimum legal size in the Coromandel fishery) was predicted to be 4676 t greenweight or 595 t meatweight (median projected values) with c.v.s of 22 and 24%, respectively. These estimates are sensitive to assumptions about dredge efficiency, growth and mortality between survey and season, expected recovery of meatweight from greenweight, exclusion of areas of low scallop density, and relate to the surveyed beds only. These results suggest a continuation of the decline in the Coromandel fishery recruited biomass since about 2005–06, with the biomass in 2009 having dropped below the level of the long-term average (1980 to present) for the first time since 2003. Most (about 68%) of this biomass was held in the Mercury Islands beds, which collectively form the mainstay of the fishery, with about 22% held in beds at Little Barrier, 8% at Colville, and only 3% at the Bay of Plenty.

Current Annual Yield (CAY) was estimated for two scenarios, by applying two different estimates of a reference rate of fishing mortality ($F_{0.1}$) to the 2009 estimates of start-of-season absolute recruited biomass. Incorporating only the direct incidental effects of fishing (on growth and mortality of adult scallops) and assuming average values for important assumed variables, CAY for the 2009 start-of-season was estimated to be 190 t meatweight. Incorporating direct and indirect incidental effects of fishing (putative habitat effects on juvenile mortality) reduced the CAY estimate to 129 t meatweight. For both scenarios, the estimates of CAY would have c.v.s at least as large as those of the estimates of start-of-season recruited biomass (22–24%), are sensitive to assumptions about dredge efficiency, growth and mortality, expected recovery of meatweight from greenweight, exclusion of areas of low scallop density, and relate to the surveyed beds only. There is also additional uncertainty associated with using single point estimates of $F_{0.1}$ (i.e., variance associated with each point estimate was not incorporated in the analysis). Further, the second approach to estimating CAY which includes direct and indirect effects of fishing is also sensitive to the duration of any habitat-mediated increase in juvenile mortality. Substantial uncertainty remains in this stock assessment, and future research and management should be aimed at reducing this uncertainty.

Bycatch from the survey was examined as a means of identifying and mapping the distribution of benthic habitats. Catches were quantified by volume of different component categories. Scallops made up the largest component of the live catch, although assorted shell made the largest contribution to the total dredge catch. Categories considered to be sensitive to dredging were caught relatively rarely. Catch compositions were analysed with multivariate techniques to divide stations into habitat groups. This approach was successful in identifying groups, although results varied with data included in the analysis, and the transformation applied.

1. INTRODUCTION

1.1 Overview

This report summarises research and fishery information for scallops (*Pecten novaezelandiae*) in the Coromandel fishery (SCA CS). The results of a Coromandel scallop biomass survey undertaken in May 2009 are summarised and yield estimates for 2009 are derived using methods detailed by the Ministry of Fisheries Science Group (2006). Unlike in recent years (e.g., 2007, see Williams (2008), MFish did not require a biomass survey and stock assessment of Northland scallops (SCA 1) in 2009.

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

1) to carry out a survey in about May/June 2009 to estimate the absolute abundance and population size frequency of scallops in the main scallop beds. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance was 20%.

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

3) to make an assessment of the bycatch taken during the survey in Objective 1, and to design a bycatch monitoring programme.

1.2 Description of the northern scallop fisheries

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

In the Coromandel fishery, commercial scallop fishing is conducted within a number of discrete beds around Little Barrier Island, east of Waiheke Island (though not in recent years), at Colville, north of Whitianga (to the west and south of the Mercury Islands), and in the Bay of Plenty (principally off Waihi, and around Motiti and Slipper Islands). Fishing in the Northland fishery is within discrete beds in Spirits Bay, Tom Bowling Bay, Great Exhibition Bay, Rangaunu Bay, Doubtless Bay, Stephenson Island, the Cavalli Passage, Bream Bay, the coast between Mangawhai and Pakiri Beach, and to the north of Little Barrier Island. Recreational and Maori customary fishing is undertaken in suitable areas throughout both fisheries, more especially in enclosed bays and harbours, many of which are closed to commercial fishing.

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

100 mm for the Northland fishery and for all non-commercial fishers. The fishing year applicable to northern scallop fisheries is from 1 April to 31 March. The commercial scallop fishing season runs from 15 July to 21 December in the Coromandel fishery, and from 15 July to 14 February in the Northland fishery.

1.3 Literature review

General descriptions of the biology of the New Zealand scallop, *Pecten novaezelandiae*, were given by Bull (1988) and Cryer (1994), and little new information on the biology has become available subsequently other than PhD theses by Morrison (1997) and Williams (2005), and some papers on reproductive ecology (Williams & Babcock 2004, 2005). The New Zealand scallop is one of several species of "fan shell" bivalve molluscs found in New Zealand waters. They have a characteristic round shell with a flat upper valve and a deeply concave lower valve. Scallops inhabit waters to about 60 m deep (to 85 m in the Chatham Islands), but are more common in the Coromandel fishery in depths of 10 to 30 m and in the Northland fishery in depths of 20 to 50 m. Growth rates are spatially and temporally variable; growth to 100 mm takes between 1.5 and 3.5 years. The maximum age of scallops in unexploited populations is thought to be about 6 or 7 years.

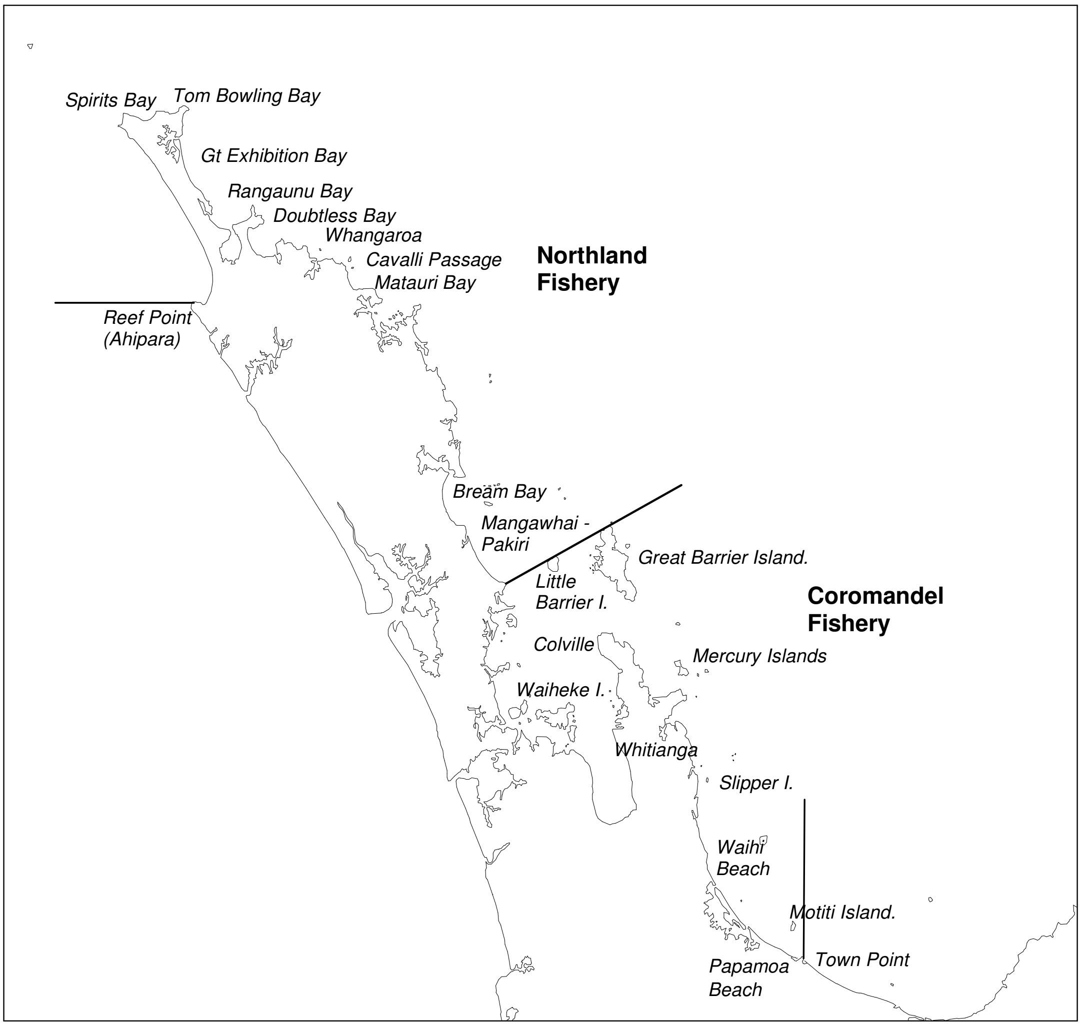


Figure 1: Geographic distribution of the two northern scallop fisheries and the names of locations mentioned in the text. After Cryer & Parkinson (2006).

Pecten novaezelandiae is hermaphroditic; each individual carries both male and female gonads at the same time. Most individuals are sexually mature at about 70 mm shell length (see Williams (2005) and Williams & Babcock (2005) for a comprehensive treatment in the Hauraki Gulf), although larger individuals have disproportionately larger gonads. They are extremely fecund and can spawn several times each year (Williams & Babcock 2004), although not all spawning events lead to successful spat settlement. Larval development lasts for about three weeks, depending on water temperature. Initial spat settlement is by byssus thread attachment to some surface free of sediment (shell hashes, hydroids, spat bags, etc.). The characteristic scallop shell does not develop until a few days after the spat loses the byssus thread and settles to the seabed.

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

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

2. REVIEW OF THE COROMANDEL FISHERY

2.1 TACCs, catch, landings, and effort data

Coromandel scallops (SCA CS) were introduced into the Quota Management System (QMS) on 1 April 2002 with a Total Allowable Catch (TAC) of 48 t, comprised of a Total Allowable Commercial Catch (TACC) of 22 t, allowances of 7.5 t for recreational fisheries and 7.5 t for customary fisheries, and an allowance of 11 t for other sources of mortality (values all in meatweight). The fishery is managed using individual transferable quotas (ITQs) that are proportions of the TACC. The fishery has been gazetted on the Second Schedule of the Fisheries Act 1996 which specifies that, for certain “highly variable” stocks, the Annual Catch Entitlement (ACE) can be increased within a fishing season. The TACC is not changed by this process and the ACE reverts to the level of the TACC at the end of each season (15 July to 21 December). Catch rates are variable both within and among seasons, but the relationship between biomass and catch per unit effort (CPUE) is complex and (declines in) CPUE cannot be used to estimate biomass within a season (Cryer 2001). Effort data, therefore, are not presented.

Since 1980, when the fishery was considered to be fully developed, commercial landings have varied more than 30-fold from less than 50 t to over 1500 t greenweight (Table 1). Since 2002 when SCA CS entered the QMS, landings have been close or equal to the catch limit set, except for in 2007 when landings were only 55% of the agreed catch limit. Commercial fishers reported three main reasons for landing less than the expected catch in 2007: 1) frequent easterly storms reduced the number of fishing days; 2) scallop meatweight condition was generally poor, possibly as a result of spawning induced by the storms; and 3) fishers jointly agreed to end the season early (in November rather than December) because of concerns about the unusually large number of pre-recruit scallops they were catching. Stopping fishing would protect these scallops from potential damage by dredging, with the view that they could survive and grow into the recruited biomass for the 2008 season. Landings in the 2008 season were 71 t meatweight, representing 75% of the agreed available catch limit (95 t).

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

			Landings (t)							
	Catch limits (t)		MHR	LFRR	CELR		Scaled estimated catch (t green)			
Season	Meat	Green[1]	Meat	Meat	Meat	Green	Barrier	Hauraki	Mercury	Plenty
1974	–	–	–	–	–	26	0	0	26	0
1975	–	–	–	–	–	76	0	0	76	0
1976	–	–	–	–	–	112	0	0	98	14
1977	–	–	–	–	–	710	0	0	574	136
1978	–	–	–	–	–	961	3	164	729	65
1979	–	–	–	–	–	790	51	282	362	91
1980	–	–	–	–	–	1 005	23	249	690	77
1981	–	–	–	–	–	1 170	41	332	743	72
1982	–	–	–	–	–	1 050	49	687	385	80
1983	–	–	–	–	–	1 553	120	687	715	31
1984	–	–	–	–	–	1 123	62	524	525	12
1985	–	–	–	–	–	877	82	518	277	0
1986	–	–	–	162	–	1 035	305	135	576	19
1987	–	–	–	384	–	1 431	136	676	556	62
1988	–	–	–	182	–	1 167	234	19	911	3
1989	–	–	–	104	–	360	95	24	253	1
1990	–	–	–	153	–	903	114	98	691	0
1991	–	–	–	203	–	1 392	98	*472	822	0
1992-93	154	1 232	–	147	–	901	68	67	686	76
1993-94	132	1 056	–	62	–	455	60	11	229	149
1994-95	66	528	–	49	–	323	48	17	139	119
1995-96	86	686	–	88	79	574	176	25	323	50
1996-97	88	704	–	81	80	594	193	25	359	18
1997-98	105	840	–	94	89	679	165	26	473	15
1998-99	110	880	–	37	37	204	2	1	199	1
1999-00	31	248	–	6	7	47	17	0	12	18
2000-01	15	123	–	8	10	70	2	0	24	44
2001-02	22	176	–	22	20	161	85	1	63	12
2002-03	35	280	32	32	31	204	12	0	79	112
2003-04	58	464	58	58	56	451	13	63	153	223
2004-05	78	624	78	78	78	624	27	27	333	237
2005-06	118	944	119	119	121	968	75	21	872	0
2006-07	118	944	118	118	117	934	60	28	846	0
2007-08	108	864	59	59	59	471	45	51	373	2
2008-09	95	760	71	71	72	541	12	15	509	5

2.2 Other information

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

2.3 Recreational and Maori customary fisheries

There is a strong non-commercial (recreational and Maori customary) interest in scallops in suitable areas throughout the Coromandel fishery, mostly in enclosed bays and harbours. Scallops are usually taken by diving using snorkel or scuba, although considerable amounts are also taken using small dredges. In some areas, especially in harbours, scallops can be taken by hand from the shallow subtidal and even the low intertidal zones (on spring tides), and, in storm events, scallops can be cast onto lee beaches in large numbers. One management tool for northern scallop fisheries is the general spatial separation of commercial and amateur fisheries through the closure of harbours and enclosed waters to commercial dredging. There remain, however, areas of contention and conflict, some of which have been addressed using additional regulated closures. Regulations governing the recreational harvest of scallops from SCA CS include a minimum legal size of 100 mm shell length and a restricted daily harvest (bag limit) of 20 per person. A change to the recreational fishing regulations in 2005, allows divers operating from a vessel to take scallops for up to two nominated safety people on board the vessel, in addition to the catch limits for the divers. Until 2006, the recreational scallop season ran from 15 July to 14 February, but in 2007 the season was changed to run from 1 September to 31 March. There is no overall catch limit for the non-commercial sector.

A pilot study was conducted in 2007–08 to assess the feasibility of estimating the recreational catch in that part of the Coromandel scallop fishery from Cape Colville to Hot Water Beach (Holdsworth & Walshe 2009). The study was based on an access point (boat ramp) survey using interviewers to collect catch and effort information from returning fishers, and was conducted from 1 December 2007 to 28 February 2008 (90 days) during the peak of the scallop season. The total estimated harvest during the survey period was 205 400 scallops (c.v. = 8.6%), with an estimated 23.9 t greenweight harvested (about 3 t meatweight).

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

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

Year	Number of scallops	c.v.	Weight (t green)	Reference
1993–94	626 000	0.14	60.0–70.0	Bradford (1997)
1996	614 000	0.12	62.0	Bradford (1998)
1999–2000	257 000	1.01	30.1	Boyd & Reilly (2005)
2000–01	472 000	0.47	55.3	Boyd et al. (2005)

Given the above concerns about the reliability of fishery-wide non-commercial harvest estimates, it is difficult to make comparisons between the levels of commercial and non-commercial scallop harvest. However, in 1993–94 the recreational harvest from the Coromandel scallop fishery was an estimated 60–70 t greenweight (Bradford 1997). These estimates may include some Maori customary catch. Commercial landings in the most comparable period (July to December 1994 scallop season) were 323 t, suggesting that, in that year, the recreational catch of scallops was about 16–18% of total removals. It is not known if these estimates were typical of the recreational catch, but the commercial catch was very low and 1993–94 may not have been a typical year. It is likely that the current non-commercial catch is higher than in the 1990s because of an increased human population. The shift in the non-commercial open season (since 2007) has enabled fishers to take scallops later in the summer (mid to late February and March); the typically settled weather and warm sea temperatures at this time of year might encourage more people to harvest scallops.

2.4 Other sources of fishing mortality

Quantitative information is available on the incidental impacts on scallop growth and mortality of encounters with commercial dredges of several designs (Cryer & Morrison 1997). The box dredges in use in the Coromandel commercial fishery have been found to be considerably more efficient than ring-bag or Keta-Ami dredges in the generally sandy conditions prevalent in the fishery. However, scallops encountered by box dredges showed modest reductions in growth rate compared with scallops collected by divers, and their mortality was high (up to about 50% for larger size classes). Stochastic modelling suggested that, of the three dredge designs tested, box dredges would generate the greatest yield-per-recruit and catch rates, and that the current MLS of 90 mm was close to optimal (for maximising long term average landings) for the Coromandel fishery (Cryer & Morrison 1997).

Individual-based population modelling and yield-per-recruit analyses strongly suggest that incidental effects, especially on mortality rates, greatly affect yield from scallop dredge fisheries (Cryer & Morrison 1997). The incidental mortality caused by dredging substantially changed the shape of yield-per-recruit curves for Coromandel scallops, causing generally asymptotic curves to become domed, and decreasing estimates of F_{max} and $F_{0.1}$. More recent field experiments (Talman et al. 2004) and modelling (see Cryer & Parkinson 2006) suggest that dredging reduces habitat heterogeneity, increases juvenile mortality, makes yield-per-recruit curves even more domed, and decreases estimates of F_{max} and $F_{0.1}$ even further.

3. RESEARCH

3.1 Stock structure

Current management assumes the Coromandel fishery is separate from the other New Zealand scallop fisheries (i.e., Northland, the various west coast harbours, Golden Bay, Tasman Bay, Marlborough Sounds, Stewart Island, and Chatham Islands). The stock structure of this fishery is assumed to be a single biological stock, although the extent to which the various beds or populations are separate reproductively or functionally is not known.

3.2 Resource surveys

3.2.1 Survey design and field methods

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

The 2009 survey of SCA CS was conducted between 11 and 22 May 2009. All sampling was undertaken by dredge, and no diving to estimate dredge efficiency was conducted. We used the same vessel and skipper as in most recent surveys. Single phase stratified random sampling was undertaken in 13 strata: Little Barrier Island (2 strata), Colville (1 stratum), the west and south of the Mercury Islands (7 strata), and the western Bay of Plenty (3 strata at Motiti Island, Papamoa Beach, and off the Katikati Entrance) (Figure 2; Appendix 1). These strata were unmodified from those used in the 2008 survey (Williams 2009), which represent the areas that were expected to contain commercial densities of scallops and be amenable to fishing. The total sampled area in 2009 was 144 km^2 (Appendix 1) compared with 119–175 km^2 between 2001 and 2008, and 253–341 km^2 between 1996 and 1999. The Coromandel fishery was not surveyed in 2000.

The survey was not formally optimised to minimise the predicted c.v. of the estimate of recruited biomass because time constraints on the survey limited the number of ways in which stations could realistically be allocated to strata. These constraints necessitated a more pragmatic approach than was used in the 1990s (e.g., Cryer & Parkinson 1999). Strata that were sufficiently close together to tackle in a single day (e.g., those around the Mercury Islands) were grouped. Up to about 20 shots can be completed in a problem-free day with little steaming, so stations were allocated to strata within groups according to their relative stratum sizes and a qualitative understanding of historical performance until the total for the group was 20–25. The positions of stations within strata were randomised using the Random Stations package (RAND_STN v 1.7 for PCs; MAF Fisheries (1990)) constrained to keep all stations at least 500 m apart. This package estimates the area of each stratum, and gives the latitude and longitude of each random station.

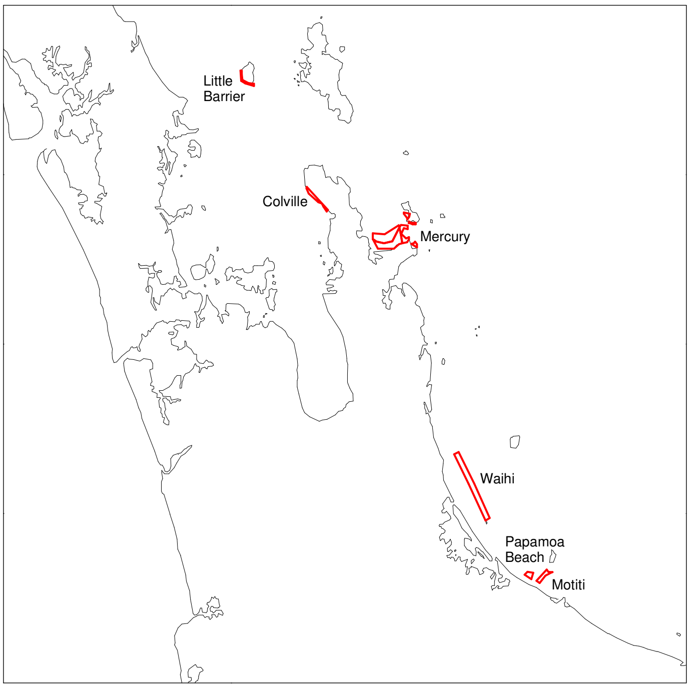


Figure 2: Location of strata for the survey of the Coromandel scallop fishery in 2009. Groups of strata are labelled with geographic descriptions used in the text (see Appendix 1 for stratum details).

Dredging in the Coromandel survey was undertaken from the chartered commercial dredge vessel *Kataraina* (whose dredge has a width of 2.0 m for which considerable historical information on dredge efficiency exists). The vessel was navigated to each station using non-differential GPS, which is sufficiently accurate (to within about 10 m) to estimate the length of even short tows. The skipper was instructed to tune his gear (select course, speed, warp length, etc.) so as to maximise his total catch at that station. Tows were nominally 0.3–0.5 nautical miles (556–926 m, assessed using non-differential GPS), depending on the expected average size of the catch. However, the dredge occasionally lost contact with the bottom or "flew" (because of hard or uneven substrates, an increase in depth, a dredge full of scallops or detritus, etc.) and, on these occasions, the tow was terminated and the actual distance travelled along the ground was estimated using GPS. At the end of each tow, the dredge was retrieved and emptied onto the sorting tray on the boat. All live scallops were separated from the detritus and bycatch, and their maximum lengths measured to the nearest millimetre rounded down. Large catches were randomly subsampled for length. All unmeasured scallops were counted. No facilities for weighing the catch at each station were available to estimate the fraction sampled by weight.

Additionally, in 2009 we categorised the dredge survey bycatch on a station by station basis. Half of the dredge contents were sorted (from one side of the sorting table to the centre) into broad taxonomic groupings (e.g., red, brown, and green seaweed, finfish and starfish species, and live and dead *Tawera spisula*, dog cockles, and horse mussels). Estimates of the relative volume of each taxonomic group in the 50% subsample were recorded for each station, as well a broad descriptor of habitat type (e.g., shell hash, rock, mud, sand, or coralline turf).

3.2.2 Estimating and correcting for dredge efficiency

We used the same methodology as in the 2005–08 scallop stock assessments to estimate and correct for dredge efficiency. This approach was described in detail by Cryer & Parkinson (2006).

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

The analytical approach to estimating start-of-season recruited biomass for scallops was developed during the 2002 and 2003 stock assessments (e.g., Cryer & Parkinson 2004) and documented in detail by Cryer & Parkinson (2006). In brief, the approach contains the following 10 steps.

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

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

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

4. The (green)weight (per unit area) of scallops at or above the minimum legal size (or other length of interest) is estimated using a length weight regression ($W = 0.00037\ L^{2.690}$). Variance associated with the regression is included by bootstrapping from the raw length-weight data.

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

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

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

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

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

10. The final step in the analysis is the prediction of meatweight from expected start-of-season greenweight. Analyses of recovery of meatweight from greenweight in the Coromandel fishery in 7 previous fishing seasons (1995 to 2002, excluding 1998) suggest that average recovery over a season varies from about 10% to about 15%. Uncertainty in predicting the meatweight recovery for the forthcoming season is incorporated by selecting one of the 7 seasonal averages for each bootstrap estimate of start-of-season recruited biomass (in greenweight).

3.2.4 2009 survey results

3.2.4.1 Coromandel fishery at the time of the survey (May 2009)

During the Coromandel survey, 15 106 of 45 553 scallops caught in 118 valid tows (sweeping an estimated 0.157 km^2) were measured (made up of the entire catch at 68 stations and 50 subsamples). Results of the bycatch sampling are presented in section 5 (see pp. 29–41 of this report). Approximate pooled length frequency distributions corrected for dredge efficiency (by assuming historical average efficiency for each substrate type) and scaled to estimated population size were constructed for the total population of the fishery (Figure 3) and the four major fishery locations (Figure 4). The largest population of scallops was found at the Mercury Islands, the recent mainstay of the fishery, which held about 68% of the total recruited population surveyed (scallops 90 mm or more shell length). Little Barrier Island scallop beds held about 22% of the total recruited population, a considerable proportion considering their relatively small area. The beds at the Mercury Islands and Little Barrier Island had relatively higher proportions of large scallops than those in Hauraki Gulf (Colville) and the Bay of Plenty (off Motiti Island, Papamoa Beach, and Waihi). There were reasonable to good proportions of smaller scallops in all beds.

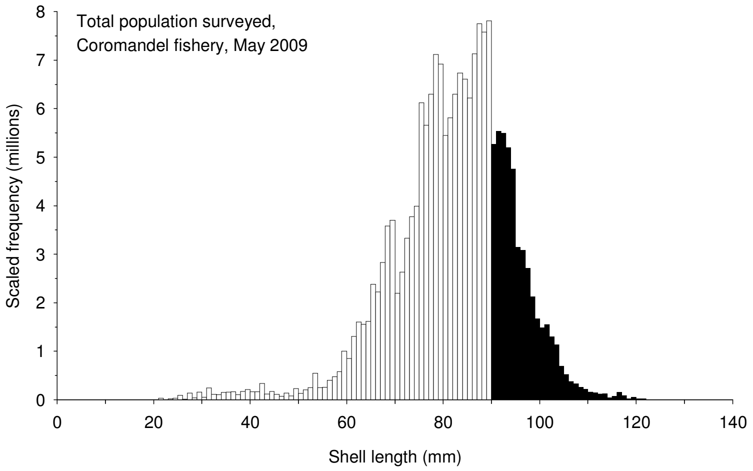


Figure 3: Length frequency distribution for the total population surveyed in the Coromandel fishery (corrected for historical average dredge efficiency), May 2009. Black bars show scallops larger than 90 mm shell length (the MLS for scallops taken commercially from the Coromandel fishery).

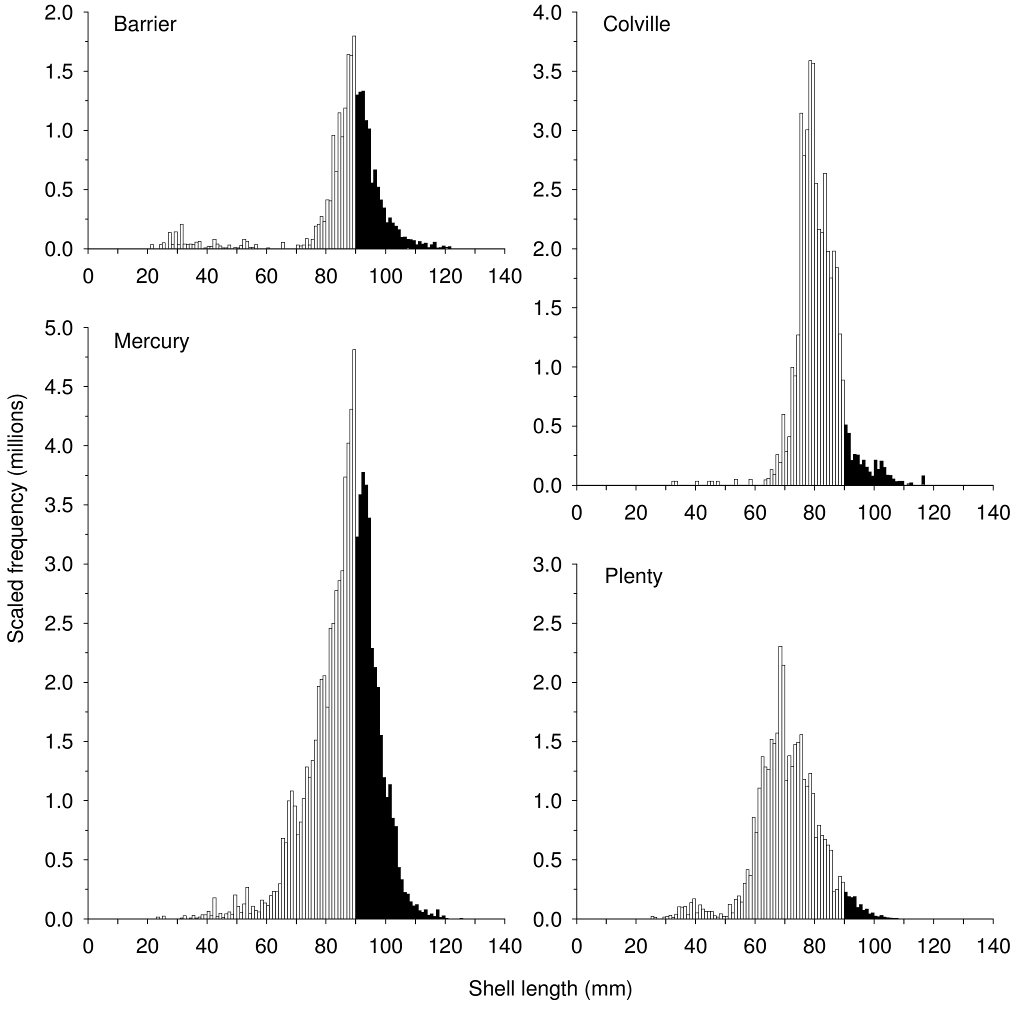


Figure 4: Length frequency distributions for the four major locations of the Coromandel fishery (corrected for historical average dredge efficiency), May 2009. Black bars show scallops larger than 90 mm shell length (the MLS for scallops taken commercially from the Coromandel fishery).

Using a simple parametric approach to estimation (including simple size-dependent scalars to correct for dredge efficiency), the biomass of scallops of 90 mm shell length or more at the time of the survey was 901 t (no correction for dredge efficiency, Table 3) or 3758 t (corrected using historical average efficiency, Table 4) with c.v.s of 12% for both estimates. These biomass estimates are reliable, but their uncertainty is grossly underestimated because this simple approach cannot incorporate additional variability associated with dredge efficiency. The biomass estimates in Table 3 (i.e., those with no correction for dredge efficiency) are the most conservative interpretation of the survey data possible and might be interpreted as the minimum absolute biomass at the time of the survey.

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

	Area (km^2)	Sites	Density (m^{-2})	SEM	c.v.	Millions	Mean wt. (g)	Biomass (kg m^{-2})	SEM	c.v.	Biomass (t green)
Barrier	4.2	16	0.5458	0.0973	0.18	2.27	81.64	44.56	7.60	0.17	186
Colville	7.6	11	0.1627	0.0496	0.31	1.24	79.49	12.93	4.11	0.32	99
Mercury	72.9	60	0.1013	0.0167	0.17	7.38	80.50	8.16	1.33	0.16	594
Plenty	59.3	31	0.0048	0.0012	0.24	0.29	76.98	0.37	0.09	0.24	22
Fishery	144.0	118	0.0777	0.0093	0.12	11.19	80.53	6.26	0.74	0.12	901

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

	Area (km^2)	Sites	Density (m^{-2})	SEM	c.v.	Millions	Mean wt. (g)	Biomass (kg m^{-2})	SEM	c.v.	Biomass (t green)
Barrier	4.2	16	2.4881	0.4731	0.19	10.36	78.57	195.49	35.65	0.18	814
Colville	7.6	11	0.4634	0.1404	0.30	3.54	81.27	37.66	11.83	0.31	288
Mercury	72.9	60	0.4469	0.0768	0.17	32.57	78.38	35.03	5.97	0.17	2 553
Plenty	59.3	31	0.0232	0.0055	0.24	1.37	75.17	1.74	0.42	0.24	103
Fishery	144.0	118	0.3323	0.0419	0.13	47.85	78.54	26.10	3.26	0.12	3 758

A more sophisticated "re-sampling" approach to variance estimation, including variability associated with the dredge efficiency scalars and length-weight regressions, produced density and biomass estimates very similar to those from the simple parametric approach (e.g., Table 4), but with higher c.v.s (e.g., a c.v. of 23% on the 'resampled' fishery-wide biomass estimate). The statistical distribution of the recruited biomass estimate (mean = 3805 t; median = 3732 t) was slightly positively skewed (Figure 5), but not markedly so.

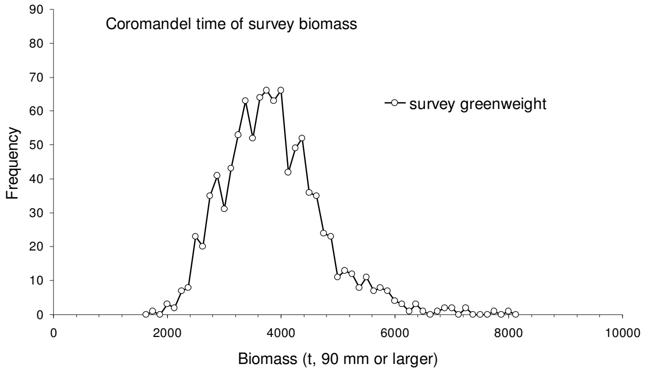


Figure 5: Frequency distribution of the estimated recruited biomass (t greenweight, scallops 90 mm or larger) in the Coromandel fishery at the time of the survey (mid May 2009). The distribution shows the results of a completely non-parametric re-sampling approach to estimating biomass (1000 bootstraps).

3.2.4.2 Trends in abundance and biomass

Discerning trends in the abundance and biomass of recruited scallops is complicated by changes to survey coverage, the establishment of closed areas, and uncertainty about dredge efficiency in any particular year. However, some changes have been so large as to transcend this combined uncertainty (Table 5). Estimates around the turn of the century (2000) were consistently at or near the lowest on record and it seems reasonable to conclude that the population was, for unknown reasons, at a very low ebb. In contrast, following reasonable increases in 2003 and, especially, 2004, the abundance and biomass in 2005 were the highest on record and probably higher than in the mid 1980s when not all of the beds were surveyed. This remarkable resurgence was strongest in the Mercury region to the north of Whitianga (the mainstay of the fishery), but most beds showed some increase in density (Figures 6, 7, and 8). There has been a gradual decline in the overall recruited population since the peak in 2005. The recruited population in 2009 was about 30% lower than that in 2008, with most of the fishable biomass held in the Mercury beds, but with a substantial amount held in high density beds at Little Barrier.

Table 5: Estimated abundance and biomass of scallops 90 mm or more shell length at the time of surveys in the five main regions of the Coromandel fishery since 1998. Survey data were analysed using a non-parametric re-sampling with replacement approach to estimation (1000 bootstraps). Figures are not necessarily directly comparable among years because of changes to survey coverage. –, no survey in a region or year. The 2001 survey totals include scallops surveyed in 7 km^2 strata at both Kawau (0.5 million, 3 t) and Great Barrier Island (0.8 million, 62 t).

Year	Abundance (millions)						Area surveyed
	Barrier	Waiheke	Colville	Mercury	Plenty	Total	(km^2)
1998	2.0	9.0	0.4	21.3	2.2	36.1	341
1999	0.5	0.5	0.0	7.3	2.7	11.2	341
2000	–	–	–	–	–	–	–
2001	7.4	0.4	–	6.9	2.1	18.1	125
2002	1.8	4.0	–	6.6	2.0	14.7	119
2003	2.5	4.0	4.3	12.3	4.9	28.6	130
2004	4.5	9.8	0.4	58.5	8.2	82.6	149
2005	6.2	3.3	3.0	118.8	12.6	145.3	174
2006	5.6	–	10.3	101.6	6.5	125.3	160
2007	4.2	1.3	4.4	59.9	14.3	84.6	175
2008	2.0	–	1.7	56.3	4.8	65.0	144
2009	10.4	–	3.1	31.8	1.3	46.9	144

Year	Biomass (t green)						Area
	Barrier	Waiheke	Colville	Mercury	Plenty	Total	(km^2)
1998	173	731	30	1 674	205	2 912	341
1999	42	34	1	559	224	873	341
2000	–	–	–	–	–	–	–
2001	554	32	–	525	165	1 362	125
2002	150	289	–	538	163	1 156	119
2003	225	302	387	995	406	2 355	130
2004	348	737	30	4 923	676	6 794	149
2005	544	274	316	10 118	1 058	12 404	174
2006	519	–	1 041	8 731	534	10 902	160
2007	376	96	409	5 498	1 110	7 539	175
2008	166	–	150	4 575	367	5 265	144
2009	823	–	257	2 512	102	3 725	144

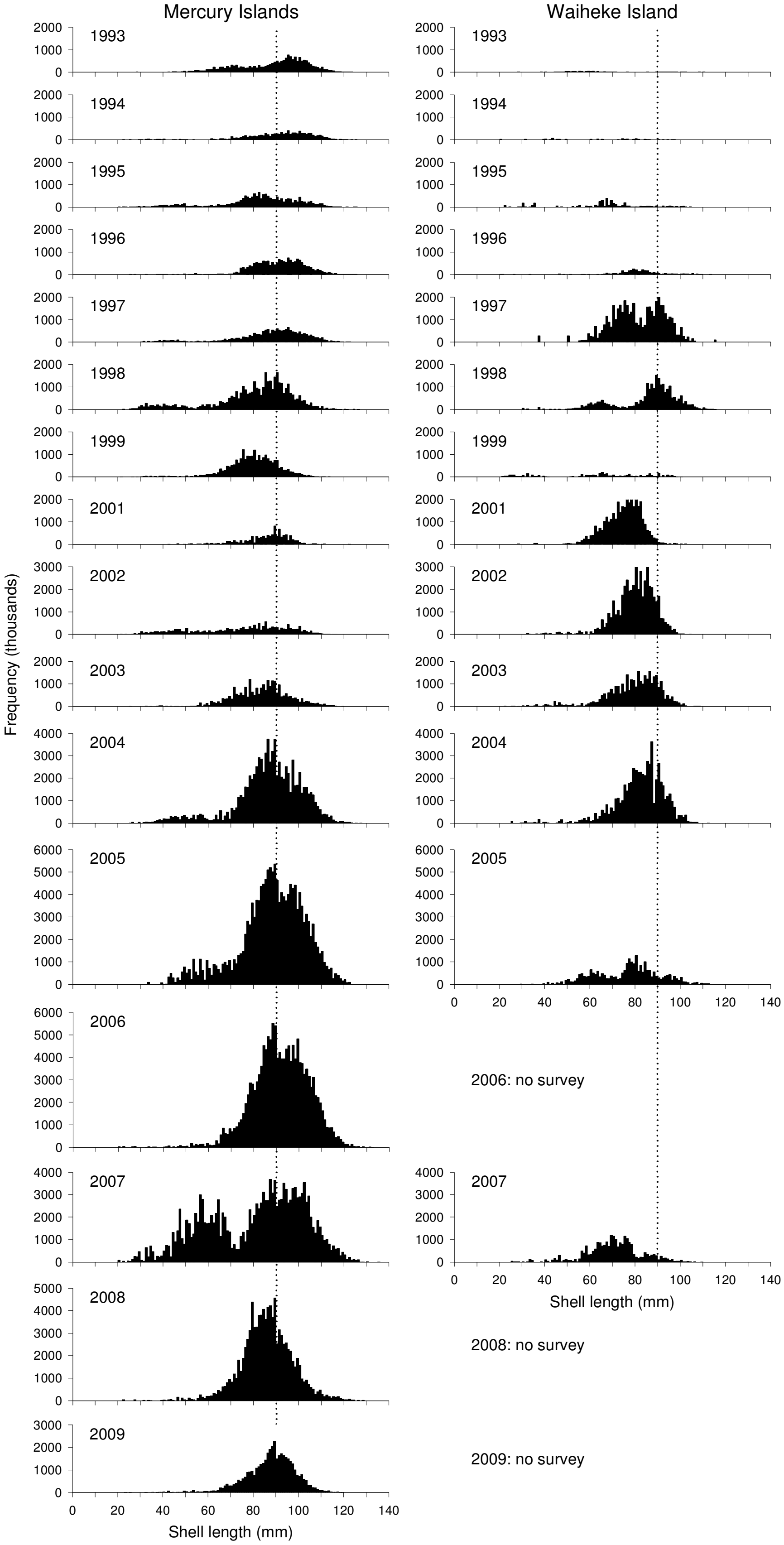


Figure 6: Scaled length frequency distributions at the time of surveys estimated using historical average dredge efficiency for scallops in the Coromandel fishery at the Mercury Islands (left) and Waiheke Island (right) since 1993. There were no surveys in 2000, and the Waiheke Island stratum was not surveyed in 2006, 2008, or 2009. Vertical dotted lines indicate the minimum legal size of 90 mm shell length.

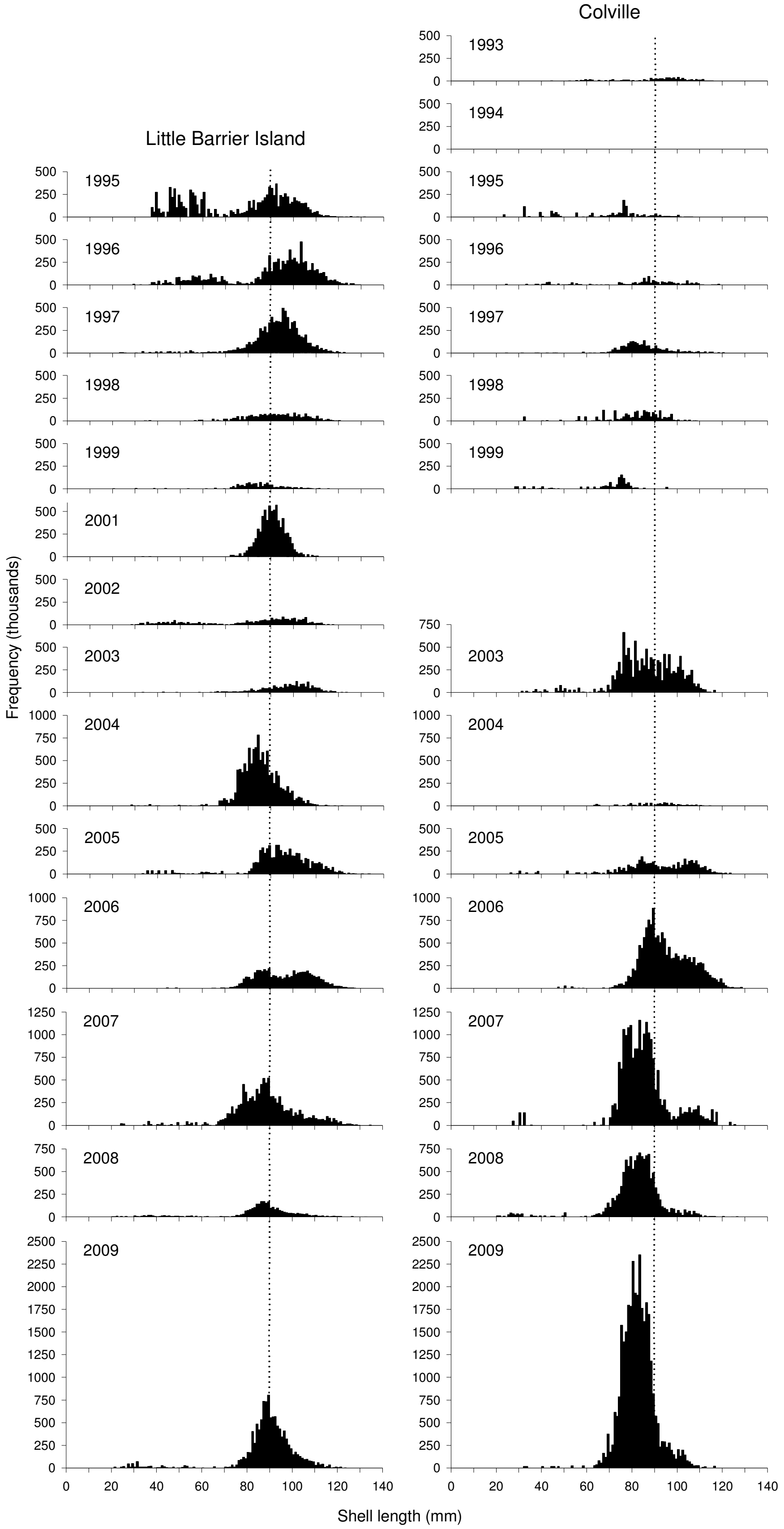


Figure 7: Scaled length frequency distributions at the time of surveys estimated using historical average dredge efficiency for scallops in the Coromandel fishery at Little Barrier Island (left) and Colville (right) since 1993. The fishery was not surveyed in 2000, and Colville was not surveyed in 2001 and 2002. Vertical dotted lines indicate the minimum legal size of 90 mm shell length.

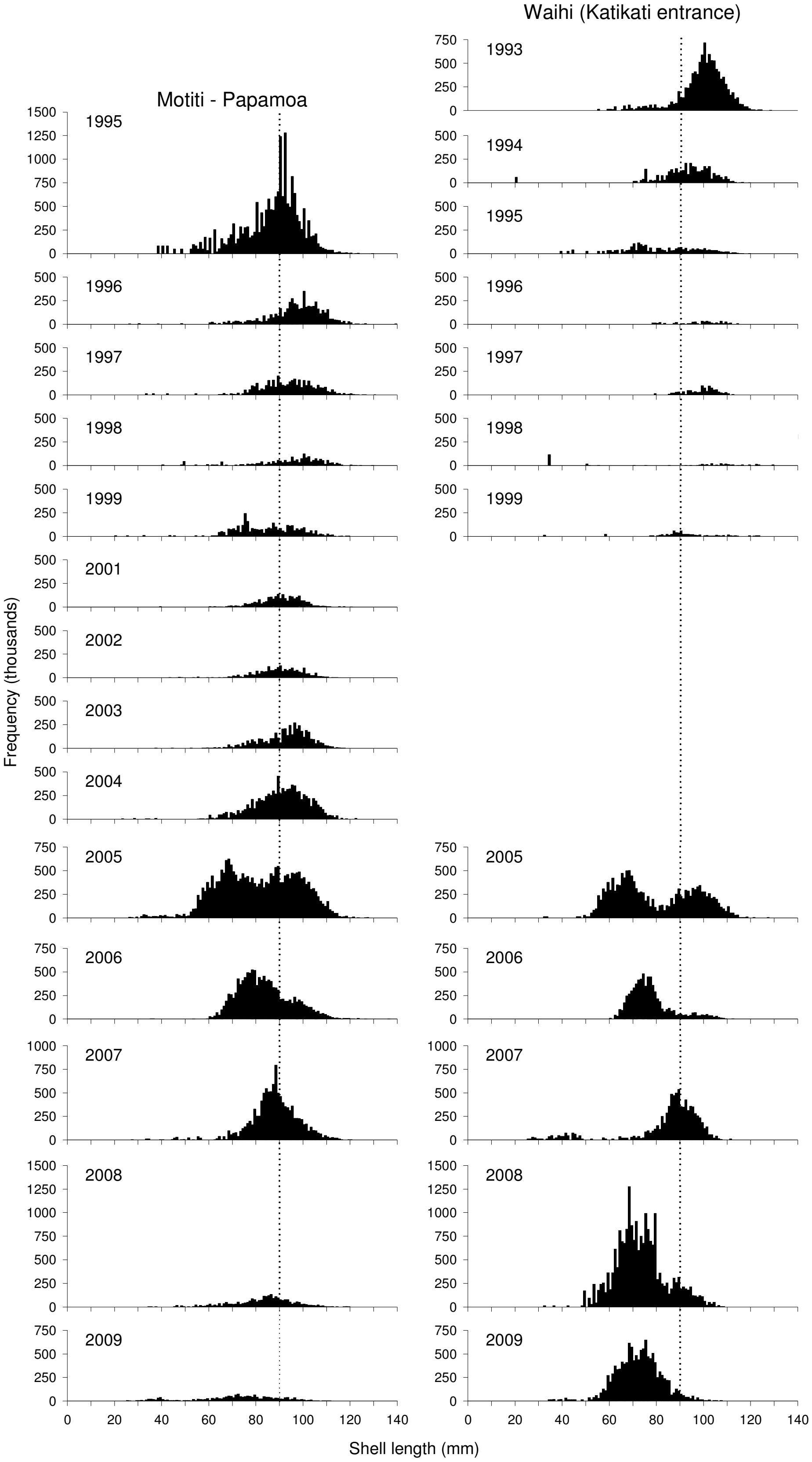


Figure 8: Scaled length frequency distributions at the time of surveys estimated using historical average dredge efficiency for scallops in the Coromandel fishery at Motiti-Papamoa (left) and Waihi (right) since 1993. The SCA CS fishery was not surveyed in 2000, and Waihi was not surveyed between 2000 and 2004. Vertical dotted lines indicate the minimum legal size of 100 mm shell length.

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

The projected biomass of scallops 90 mm shell length or more at the start of the season (15 July 2009) was estimated assuming historical average dredge efficiency at length, average growth (from previous tagging studies), and M = 0.5 spread evenly through the year. This approach produced an estimated start of season biomass of 4676 t greenweight (median projected value) with a c.v. of 22% (Table 6), thereby predicting a large increase (of about 25%) in recruited biomass between survey and season (Figure 9). Further, assuming historical average recovery of meatweight from greenweight led to an estimate of 595 t meatweight (median projected value) with a c.v. of 24% (Table 6). The average weight of a recruited scallop in Coromandel in 2009 was projected to decline from about 79 to 73 g by the start of the season (Table 6). Together, these results could be explained by the large number (tens of millions) of pre-recruit scallops (just smaller than 90 mm) at the time of the survey growing into the recruited biomass by the start of the season. Further growth of pre-recruit scallops during the 2009 season could see additional recruitment to the fishable biomass.

Table 6: Mean and median projected number and biomass of scallops 90 mm shell length or more in the Coromandel fishery at the start of the season assuming historical average dredge efficiency at length, average growth (from previous tagging studies), M = 0.5 spread evenly through the year, and average recovery of meatweight from greenweight.

	Surveyed area (km^2)	Millions of scallops		Scallop weight (g)	Greenweight biomass (t)			Meatweight biomass (t)		
		Mean	Median	Mean	Mean	Median	c.v.	Mean	Median	c.v.
Barrier	4.2	13.80	13.17	73.55	1 015	978	0.29	128	122	0.33
Colville	7.6	8.39	7.66	67.47	566	521	0.49	72	65	0.52
Mercury	72.9	41.57	40.06	73.70	3 064	2962	0.26	390	376	0.29
Plenty	59.3	2.60	2.52	66.47	173	167	0.29	22	21	0.34
Fishery	144.0	66.36	64.52	72.60	4 818	4676	0.22	612	595	0.24

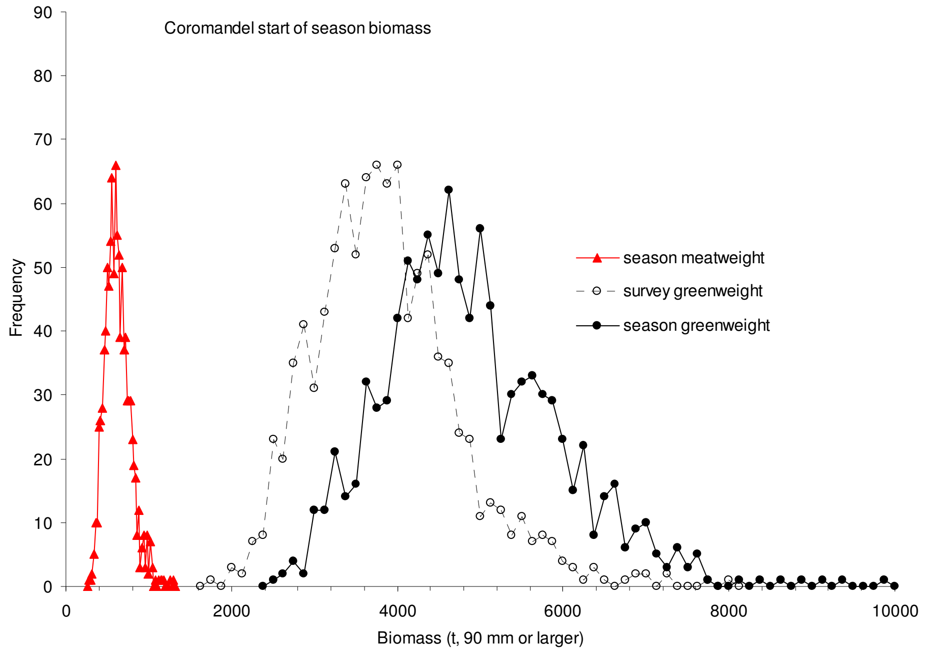


Figure 9: Frequency distributions of estimated recruited biomass (90 mm or larger) in the Coromandel fishery at the start of the season (mid July 2009). The results of a completely non-parametric re-sampling and projection approach are shown for the start of the season in t greenweight (closed circles, solid line) and meatweight (closed triangles, solid line). The results of the time of survey analysis in t greenweight (open circles, dashed line) are also shown for comparison.

3.2.4.4 Sensitivity of Coromandel biomass to exclusion of areas of low scallop density

Most recent stock assessments of New Zealand scallops have explored the sensitivity of biomass estimates to exclusion of areas of low scallop density, and it has generally been accepted that 0.04 m^{-2} (one recruited scallop for each 25 m^2 of seabed) is a reasonable working definition for the limit of acceptable fishing. Working at a station level, therefore, the biomass estimates at the time of the survey were recalculated assuming that all stations where scallops were scarcer than 0.04 m^{-2} had zero density, and stations where scallops were denser than 0.04 m^{-2} had a density of the actual density minus 0.04 m^{-2}. These corrections were applied before any scaling for dredge efficiency, so they are conservative.

Excluding areas of low density (below 0.04 m^{-2}) reduced the fishery-wide biomass estimates at the time of the survey by about 22% (Figure 10). Excluding areas where the density was less than 0.08 m^{-2} reduced the fishery-wide biomass estimates by about 39% (although 0.08 m^{-2} is quite a high density by historical standards).

In 2009, the effect of excluding areas of low density from biomass estimates was dramatic only in the Bay of Plenty beds (Figure 11), where the biomass estimate declined by 99% when areas where scallops were less dense than 0.04 m^{-2} were excluded. Thus, virtually all of the biomass in the Bay of Plenty beds appeared to be contained in areas of relatively low density where catch rates may not be very good. However, the Bay of Plenty beds contained only an estimated 3% of the total biomass of the Coromandel fishery in 2009.

Where the mean density of scallops was high at Little Barrier Island, Colville, and the Mercury Islands (where the vast majority of the biomass was concentrated), the biomass estimates were much less affected when areas where scallops were less dense than 0.04 m^{-2} were excluded. At Little Barrier, where the mean density of scallops was by far the highest, the biomass estimate declined by only about 7%, whereas at Colville and the Mercury Islands, locations with reasonably high densities of scallops, the biomass estimate declined by about 22–25% when areas where scallops were less dense than 0.04 m^{-2} were excluded.

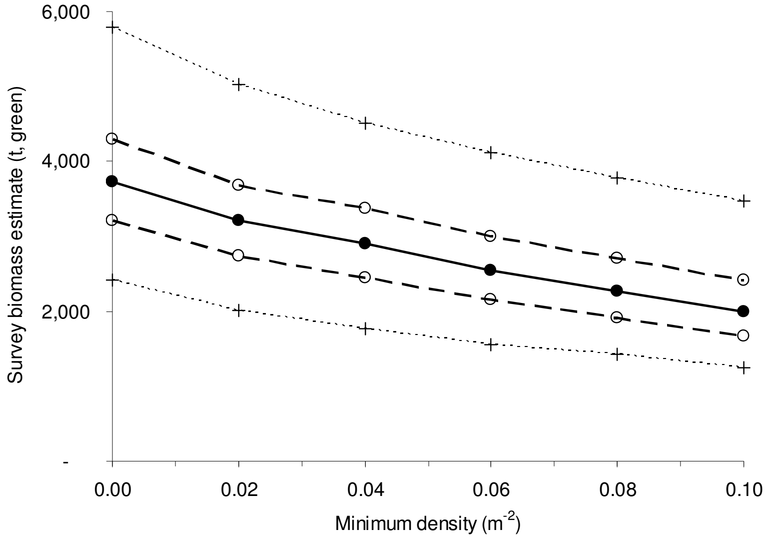


Figure 10: Effect of excluding areas of low scallop density on the fishery-wide biomass estimate in the Coromandel fishery at the time of the survey (May 2009). For increasing minimum acceptable densities (un-scaled for dredge efficiency) the median biomass estimates (solid line, closed circles) corrected for average historical dredge efficiency are given together with their quartiles (dashed lines) and 95% confidence range (dotted lines).

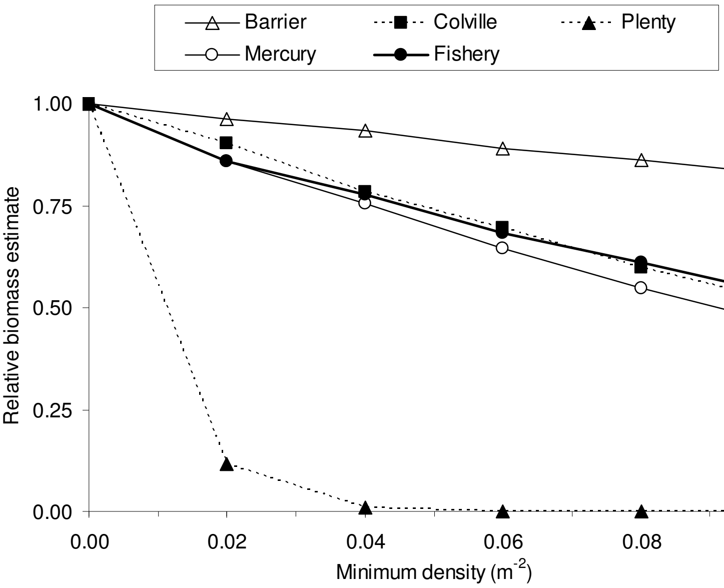


Figure 11: Effect of excluding areas of low scallop density on biomass estimate by bed in the Coromandel fishery at the time of the survey (May 2009). For increasing minimum acceptable densities (un-scaled for dredge efficiency) the median biomass estimates (corrected for historical average dredge efficiency) for each area surveyed are given.

The effect of excluding areas of low density from the start of season biomass estimates was also explored. First, as described above, it was assumed that all stations where scallops were scarcer than 0.04 m^{-2} had zero density, and stations where scallops were denser than 0.04 m^{-2} had a density of the actual density minus 0.04 m^{-2}. These corrections were applied to the survey data before any scaling for dredge efficiency, so they are conservative. Second, the time of survey population was projected forward to the start of the season (15 July 2009) assuming historical average dredge efficiency at length, average growth (from previous tagging studies), and M = 0.5 spread evenly through the year (i.e., exactly the same projection methodology as used in Section 3.2.4.3). This approach produced an estimated start of season biomass of 3555 t greenweight (median projected value) with a c.v. of 25%; assuming historical average recovery of meatweight from greenweight led to an estimate of 452 t meatweight (median projected value) with a c.v. of 27% (Table 7).

Table 7: Mean and median projected number and biomass of scallops 90 mm shell length or more in the Coromandel fishery at the start of the season by excluding areas of low density (where scallops were scarcer than 0.04 m^{-2}) and assuming historical average dredge efficiency at length, average growth (from previous tagging studies), M = 0.5 spread evenly through the year, and average recovery of meatweight from greenweight.

	Surveyed area (km^2)	Millions of scallops		Scallop weight (g)	Greenweight biomass (t)			Meatweight biomass (t)		
		Mean	Median	Mean	Mean	Median	c.v.	Mean	Median	c.v.
Barrier	4.2	12.85	12.32	73.50	945	917	0.31	120	115	0.32
Colville	7.6	6.61	5.99	67.75	448	406	0.49	56	51	0.52
Mercury	72.9	30.87	29.33	74.08	2 287	2 180	0.30	292	278	0.34
Plenty	59.3	0.02	0.02	71.56	1	1	0.70	0	0	0.73
Fishery	144.0	50.36	48.55	73.10	3 681	3 555	0.25	468	452	0.27

3.3 Biomass estimates

Estimates of current (2009) biomass are described above; the recruited biomass of scallops 90 mm in shell length or greater at the start of the 2009 season (15 July 2009) in the Coromandel fishery was predicted to be 4676 t (greenweight) and 595 t (meatweight) (median projected values; Table 6). Given the highly variable nature of scallop populations, the concept of virgin biomass is probably not meaningful, but average (recruited) biomass could be estimated from the data presented in the tables.

3.4 Yield estimates

3.4.1 Reference rates of fishing mortality

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

3.4.2 Estimation of Maximum Constant Yield (MCY)

MCY is not normally estimated for scallops and, given the highly variable nature of most wild scallop fisheries, is likely to be close to zero. Cryer et al. (2003) showed that constant catch strategies for scallops produced lower yield at much higher biological risk than strategies wherein catch was varied as biomass varied.

3.4.3 Estimation of Current Annual Yield (CAY)

Management of Coromandel scallops is based on a CAY approach. Since 1998, catch limits have been adjusted in line with estimated start-of-season recruited biomass and an estimate of CAY made using the Baranov catch equation:

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

where $t = 5/12$ years, F_{ref} is a reference fishing mortality ($F_{0.1}$) and B_{jul} is the estimated start-of-season (15 July) recruited biomass (scallops of 90 mm or more shell length). Natural mortality is assumed to act in tandem with fishing mortality for the first 5 months of the fishing season, the length of the current Coromandel commercial scallop season. B_{jul} is estimated assuming historical average dredge efficiency at length, average growth (from previous tagging studies), $M = 0.5$ spread evenly through the year, and historical average recovery of meatweight from greenweight. Because of the uncertainty over biomass estimates, growth, and mortality in a given year, and appropriate reference rates of fishing mortality, yield estimates must be treated with caution.

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

1) CAY including direct effects on adults

By including only the direct incidental effects of fishing on scallops, Cryer et al. (2004) derived an estimate of $F_{0.1} = 1.034$ (reported by Cryer et al. (2004) as $5/12 * F_{0.1} = 0.431$). Using this value and the 2009 start of season biomass estimates (median projected values), CAY for 2009–10 was estimated to be 1489 t greenweight or 190 t meatweight.

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

Cryer et al. (2004) modelled the "feedback" effects of habitat modification by the dredge method on juvenile mortality in scallops. They developed estimates of F_{ref} that incorporated such effects, but had to make assumptions about the duration of what they called the "critical phase" of juvenile growth during which scallops were susceptible to increased mortality. To give some guidance on the possible outcome of including "indirect" (as well as direct) effects on yield estimates, Cryer et al.'s (2004) estimate of $F_{0.1} = 0.658$ (reported as $5/12 * F_{0.1} = 0.274$) was applied here. Using this value and the 2009 start of season biomass estimates (median projected values), CAY for 2009–10 was estimated to be 1016 t greenweight or 129 t meatweight.

For both scenarios, the estimates of CAY would have c.v.s at least as large as those of the estimates of start-of-season recruited biomass (22–24%), are sensitive to assumptions about dredge efficiency, growth, and expected recovery of meatweight from greenweight, and relate to the surveyed beds only. The sensitivity of these yield estimates to excluding areas of low density has not been calculated, but excluding stations with scallop density less than 0.04 m^{-2} reduced the fishery-wide time of survey biomass estimate by about 22%, and the start of season biomass estimate by about 24% (depending on which beds were fished). There is also additional uncertainty associated with using a point estimate of $F_{0.1}$ (i.e., variance associated with the point estimate of $F_{0.1}$ was not incorporated in the analysis). Further, the second approach which includes indirect incidental effects (putative "habitat effects") is sensitive to the duration of any habitat-mediated increase in juvenile mortality.

Regardless of the approach used to estimate CAY, the production of a single 'best estimate' of CAY should be treated with caution; it is better to work with a range of estimates (e.g., using a confidence interval). One way to do this is to decide how confident one wishes to be that a particular CAY will not cause fishing mortality to exceed $F_{0.1}$. For example, a range of one-sided confidence intervals can be formed for CAY at different levels of confidence; the lower limit of each interval is the catch limit which gives the specified level of confidence that $F_{0.1}$ will not be exceeded (Table 8).

Table 8: Decision table to evaluate the confidence of not exceeding $F_{0.1}$ given a variety of alternative catch limits for the 2009–10 Coromandel fishing season. $F_{0.1}$ was estimated using two approaches: 1) including direct incidental effects of fishing only, and 2) including direct and indirect incidental effects of fishing.

Potential catch limit for 2009–10 (t meatweight)	Confidence (%) that fishing mortality is less than $F_{0.1}$	
	$F_{0.1}$ direct effects	$F_{0.1}$ direct and indirect effects
60	100.0	99.9
70	100.0	99.6
80	100.0	97.8
90	99.9	92.8
100	99.6	85.5
110	98.8	75.6
120	97.1	62.4
130	93.6	49.2
140	89.3	36.5
150	83.1	27.2
160	76.0	18.8
170	67.9	12.5
180	58.9	8.1
190	49.6	4.9

4. MANAGEMENT IMPLICATIONS

Estimates of current biomass for the Coromandel fishery are available from the 2009 dredge survey, but the only reference biomass that might be calculated is average recruited biomass. Scallop biomass can be expected to vary from one year to the next, so the long-run average is difficult to estimate and not necessarily a good indicator. However, biomass estimates around the turn of the century (2000) were consistently at or near the lowest on record, and it seems reasonable to conclude that the population was, for unknown reasons, at a very low ebb. In contrast, following reasonable increases in biomass, catch rate, and condition of scallops in 2003 and, especially, 2004, the biomass in 2005 (almost regardless of what was assumed about dredge efficiency) was the highest on record and probably higher than in the mid 1980s when not all of the beds were surveyed. This remarkable resurgence was strongest at the Mercury Islands beds, but most beds showed some increase in density. There has been a gradual decline in the overall fishery biomass since about 2005–06, and the biomass in 2009 had dropped below the level of the long-term average (1980 to present) for the first time since 2003. As in recent years, most of the fishable biomass was held in the Mercury Islands beds (the mainstay of the fishery), but substantial proportions were held also in beds at Little Barrier and Colville despite their relatively small areas of fishing ground. Biomass in the Bay of Plenty beds was the lowest on record.

Substantial uncertainties stemming from assumptions about dredge efficiency during the survey, rates of growth and natural mortality between survey and season, and predicting the average recovery of meatweight from greenweight remain in these stock assessments. The findings of a current research project (SCA200802) to model scallop dredge efficiency using existing data should help to reduce these uncertainties, as should future research projects aimed at collecting more data on scallop growth and mortality. Managing the fisheries based on the number of recruited scallops at the start of the season, as opposed to recruited biomass (the current approach), could remove the uncertainty associated with converting estimated numbers of scallops to estimated meatweight.

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

5. BYCATCH

Bycatch during the survey was examined as a means of identifying and mapping the distribution of benthic habitats (and particularly those thought to be sensitive to scallop dredging) in relation to the spatial distribution of the scallop fishery. This approach to collecting information about benthic habitats has not been routinely applied to New Zealand dredge fisheries in the past, and this study was undertaken as a pilot, with three separate tasks of

1. Characterising the bycatch of the survey
2. Describing the benthic habitat from the bycatch
3. Identifying appropriate approaches to employ for future sampling of bycatch

5.1 Methods

It was originally planned (as stated in the tender) to photograph the catch from a subset of representative survey tows from each area and quantify bycatch from photographs, as described in ENV200604 (Tuck et al. 2006). At the time of the survey, it was decided not to use the photographic approach, and rather than photographing the catch from a subset of stations, the catch from all stations was physically examined, with the total volume of the catch estimated, and the percentage volume by main species or group quantified. The species and groups used to categorise the dredge catches are listed in Table 9. Data are available on the total catch volume and percentage volume by main species or group for all 118 valid survey tows.

Table 9: Species and groups used to categorise dredge catches.

Type	Species or group
habitat formers	sponge, tubeworm, coralline turf
starfish	*Astropecten*, *Coscinasterias*, cushion star, carpet star
main bivalves	dog cockles, horse mussels, scallops, *Tawera* (all split into live or dead)
other benthic invertebrates	anemones, crabs, snails, polychaetes, octopus, rock lobster
fish	gobie, gurnard, John dory, lemon sole, pufferfish, red cod, sand eel, snake eel, stargazer, yellowbelly flounder
seaweed	brown seaweed & *Ecklonia*, green seaweed, red seaweed
shell	other dead shell, shell hash
substrate	mud, sand (different categories), rock
other	rubbish

As described above (Section 3.2.1), the survey tows were randomly allocated within pre-defined survey strata (see Figure 2). The survey strata were agreed with commercial Coromandel scallop fishers, prior to the survey, to represent the area likely to be fished in following season. Therefore, the areas fished can be considered to be generally representative of the scallop grounds in the region, but since fishing effort undertaken by the fishery is highly likely to be concentrated in areas of high scallop catch rate and low bycatch, the overall survey bycatch (and incidence of species within it) may not necessarily reflect the overall commercial bycatch.

5.2 Bycatch description

The catch of each category was standardised to the swept area of each tow. Total catch volume by strata is shown in Figure 12. It can be seen the overall catch volume varied considerably between survey strata, with highest catch volumes recorded in the Bumper and Sarah's strata (both in the Mercury area), and the lowest catch volumes recorded in the Bay of Plenty.

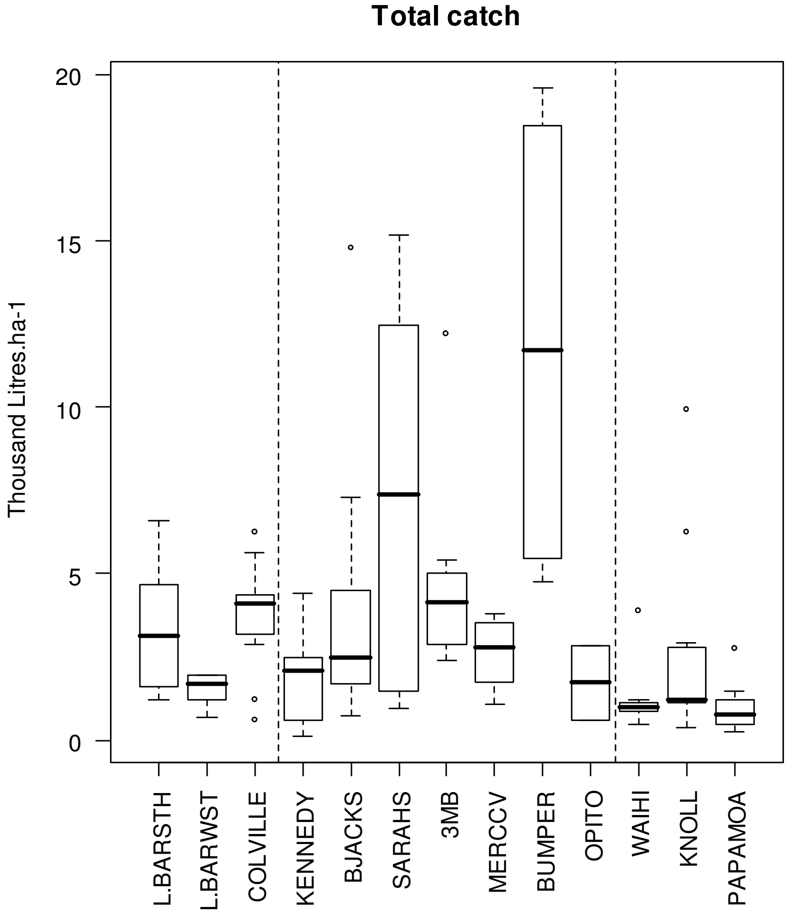


Figure 12: Boxplot of total catch volume by survey area. Vertical dashed lines between boxes split strata into Hauraki Gulf (left), Mercury (middle), and Bay of Plenty (right) areas.

Over the whole survey, scallops formed the largest live component of the total catch volume (26%), followed by assorted seaweed (11%), starfish (4%), and other live bivalves (4%). Coralline turf made up 1% of the total catch, with no other live component exceeding 0.5%. Dead shell (identifiable and hash) formed the largest overall component (45%), and rock, sand, and gravel formed 8%.

The volumes of each of the main components of the catches are shown for each stratum in Figure 13. Scallop catches were highest in the Hauraki Gulf strata, and lowest in the Bay of Plenty. Differences in other components of the catches did not show any consistent patterns, and where greater catches were recorded, these were generally at the Bumper and Sarah's strata, with the greatest overall catches. Average catch rates for the various components are also shown in Table 10.

Boxplots of the proportion of the total catch volume of each of the main components of the catches are shown for each stratum in

Figure 14. Overall percentage catch composition for each of the survey strata is also shown in Table 11. The two Little Barrier Island strata had a higher proportion of scallops in the catch than elsewhere, while Colville and Mercury Cove had intermediate levels, and the other strata were somewhat lower.

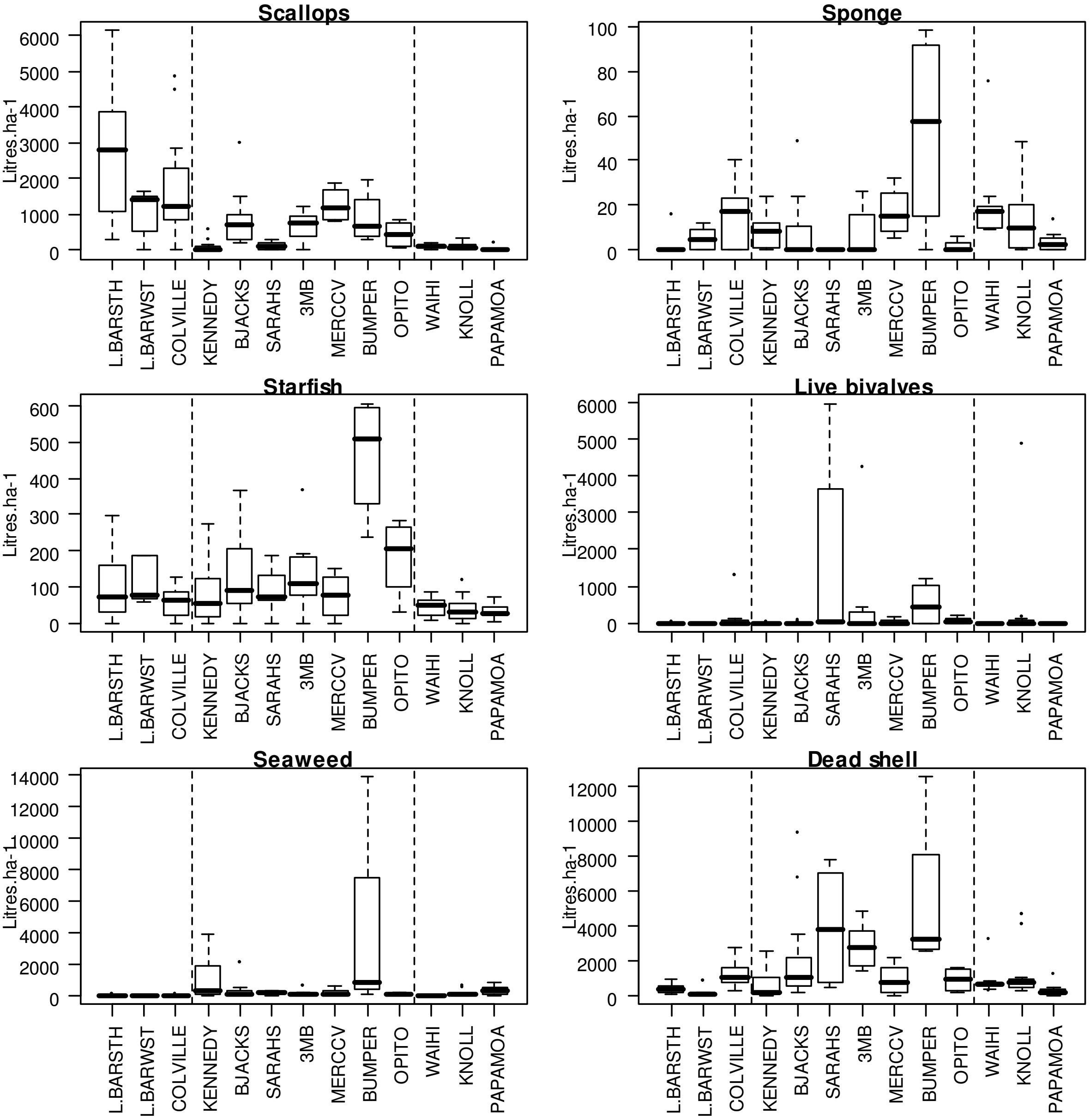


Figure 13: Boxplots of catch rate (litres.ha^{-1}) of main components of scallop survey catches, by survey area. Note scales vary between plots. Vertical dashed lines between boxes split strata into Hauraki Gulf (left), Mercury (middle), and Bay of Plenty (right) areas.

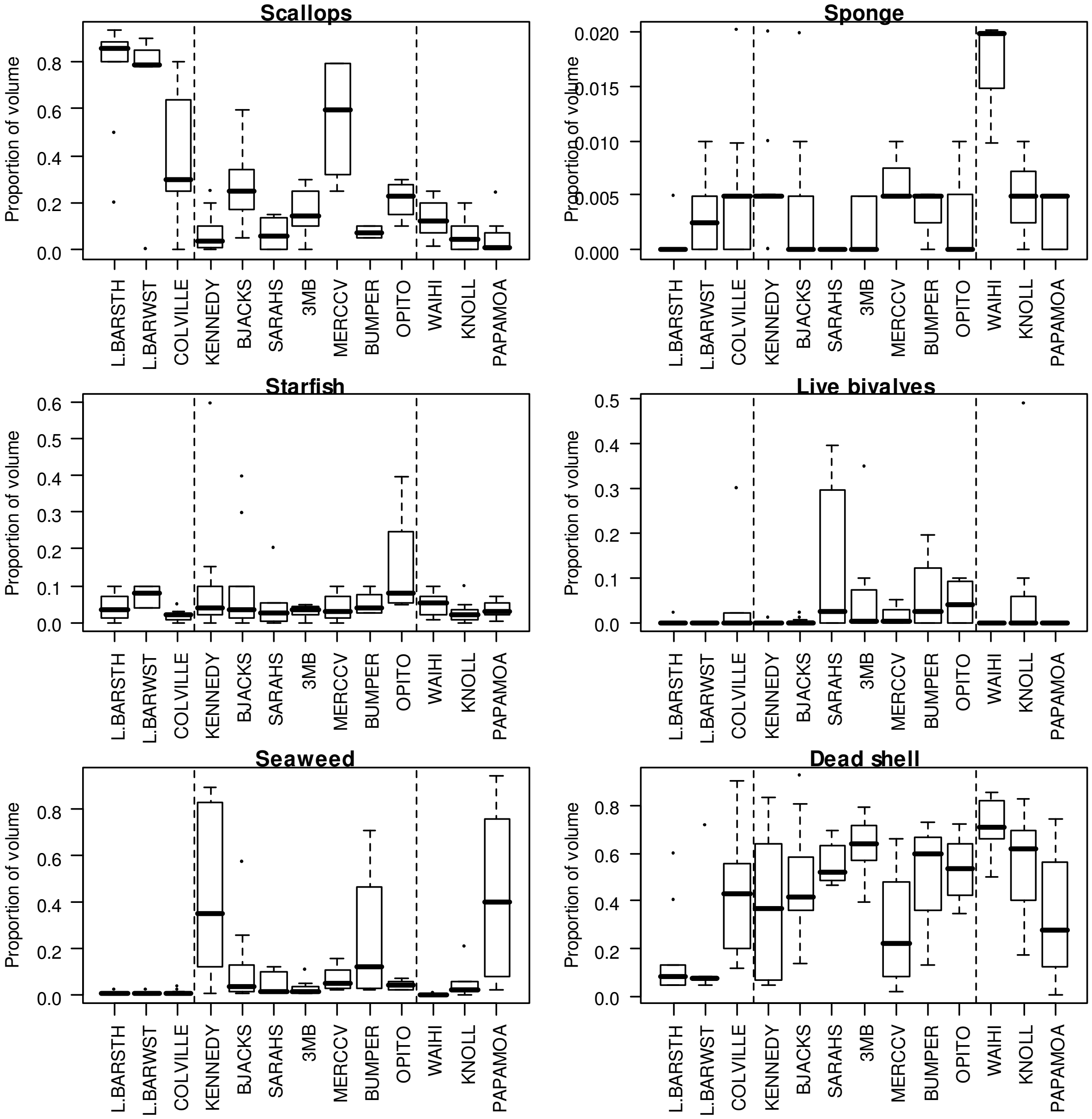


Figure 14: Boxplots of proportion of total dredge catch volume made up by main components of scallop survey catches, by survey area. Note scales vary between plots. Vertical dashed lines between boxes split strata into Hauraki Gulf (left), Mercury (middle), and Bay of Plenty (right) areas.

The percentage of tows in which the various catch components featured within each stratum is shown in Table 12. Common components caught at over 80% of stations included scallops, starfish, seaweed, other benthic organisms, dead shell, and rock/sand/gravel. Sponge was caught at just over half the stations (57%), while live bivalves (excluding scallops) were caught at just under a quarter (23%). Coralline turf was caught in four strata, and up to 75% of stations within these areas, but only at 12% of stations overall. Live horse mussels and tubeworm were caught only in one stratum, and at very low incidence overall (less than 2%).

Table 10: Table of catch rate (litres.ha^{-1}) of different bycatch categories in dredge catches from the scallop survey.

Substrate	Code	scallops	starfish	sponge	horse mussel	coralline turf	tubeworm	live bivalves	seaweed	other benthic	fish	dead shell	rock / sand gravel	rubbish	total
S	LITBARSTH	2695	101	2	0	13	0	3	25	27	6	405	54	0	3331
S	LITBARWST	1087	109	5	0	0	0	0	13	10	2	238	64	0	1529
M	COLVILLE	1746	59	15	124	0	0	18	36	43	2	1281	383	0	3707
S	KENNEDY	98	83	8	0	0	0	2	941	21	2	622	44	0	1820
S	BJACKS	779	124	7	0	0	0	9	274	32	1	1921	365	29	3541
S	SARAHS	116	88	0	0	1002	0	1612	176	62	0	3963	449	0	7469
S	3MB	673	137	7	0	94	0	610	142	50	0	2833	287	0	4833
M	MERCCV	1258	76	17	0	0	0	48	204	8	0	912	96	4	2624
S	BUMPER	897	464	53	0	479	8	516	3924	81	0	5416	119	0	11958
S	OPITO	435	182	2	0	0	0	72	81	4	0	914	15	14	1718
S	WAIHI	122	44	20	0	0	0	0	2	12	6	845	92	18	1161
S	KNOLL	104	40	13	0	0	0	470	143	26	4	1336	547	0	2683
S	PAPAMOA	36	32	4	0	0	0	0	334	11	6	338	223	0	985

Table 11: Table of overall percentage catch composition of different bycatch categories in dredge catches from the scallop survey.

Substrate	Code	scallops	starfish	sponge	horse mussel	coralline turf	tubeworm	live bivalves	seaweed	other benthic	fish	dead shell	rock / sand gravel	rubbish
S	LITBARSTH	81.8	3.0	0.0	0.0	0.3	0.0	0.1	0.7	0.8	0.2	11.4	1.6	0.0
S	LITBARWST	72.8	7.0	0.3	0.0	0.0	0.0	0.0	0.8	0.6	0.2	14.4	3.9	0.0
M	COLVILLE	43.0	1.5	0.4	3.3	0.0	0.0	0.4	1.1	1.2	0.1	37.4	11.6	0.0
S	KENNEDY	6.0	4.9	0.5	0.0	0.0	0.0	0.1	47.5	1.2	0.1	37.0	2.7	0.0
S	BJACKS	22.6	4.2	0.2	0.0	0.0	0.0	0.3	9.4	1.0	0.0	50.6	10.6	1.1
S	SARAHS	4.0	2.6	0.0	0.0	8.8	0.0	18.6	3.5	0.9	0.0	55.0	6.6	0.0
S	3MB	15.5	2.9	0.2	0.0	2.4	0.0	7.7	3.0	1.1	0.0	62.2	4.9	0.0
M	MERCCV	47.6	3.3	0.7	0.0	0.0	0.0	1.9	7.9	0.3	0.0	34.5	3.8	0.2
S	BUMPER	7.4	4.8	0.4	0.0	3.2	0.1	6.2	30.5	0.6	0.0	45.6	1.1	0.0
S	OPITO	25.3	10.6	0.1	0.0	0.0	0.0	4.2	4.7	0.2	0.0	53.2	0.9	0.8
S	WAIHI	11.8	4.2	1.7	0.0	0.0	0.0	0.0	0.2	1.1	0.5	71.9	7.0	1.7
S	KNOLL	4.6	1.9	0.5	0.0	0.0	0.0	11.5	7.2	0.9	0.2	47.7	25.5	0.0
S	PAPAMOA	3.9	3.3	0.4	0.0	0.0	0.0	0.0	34.2	1.1	0.6	34.2	22.3	0.0
Total incidence		26.2	3.7	0.4	0.3	1.1	0.0	3.5	11.1	0.9	0.1	44.2	8.1	0.4

Table 12: Table of percentage of occurrence of different bycatch categories in dredge catches from the scallop survey.

Substrate	Code	scallops	starfish	sponge	horse mussel	coralline turf	tubeworm	live bivalves	seaweed	other benthic	fish	dead shell	rock / sand gravel	rubbish
S	LITBARSTH	100	90	10	0	30	0	10	80	90	20	100	100	0
S	LITBARWST	100	100	50	0	0	0	0	83	83	17	100	100	0
M	COLVILLE	91	82	64	18	0	0	18	73	100	9	100	100	0
S	KENNEDY	100	93	86	0	0	0	7	100	79	14	100	71	0
S	BJACKS	100	90	40	0	0	0	25	100	100	10	100	75	5
S	SARAHS	67	83	0	0	50	0	50	100	100	0	100	67	0
S	3MB	100	88	38	0	63	0	50	100	100	0	100	100	0
M	MERCCV	100	75	100	0	0	0	50	100	100	0	100	100	25
S	BUMPER	100	100	75	0	75	25	50	100	100	0	100	75	0
S	OPITO	100	100	25	0	0	0	50	100	25	0	100	50	25
S	WAIHI	100	100	100	0	0	0	0	25	100	25	100	92	17
S	KNOLL	82	91	73	0	0	0	45	91	82	36	100	91	9
S	PAPAMOA	100	100	63	0	0	0	0	100	88	50	100	100	0
Total incidence		96	92	57	2	12	1	23	86	91	16	100	86	5

5.3 Identification of habitats using multivariate examination of catch composition

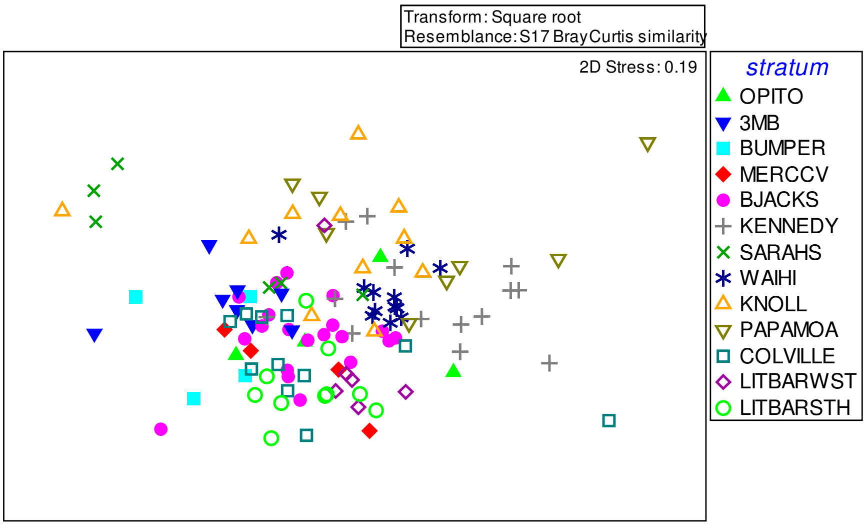
In order to examine benthic habitat distribution from the catch composition, it is necessary to assume that the various components of the catch represent the benthic habitats from which they were caught. It was therefore decided to exclude catch components that are considered particularly mobile (fish, octopus, brown seaweed, horse mussel shell, and rubbish), since they may not reflect local benthic habitat. The dredge catch composition was examined using a suite of multivariate techniques within the PRIMER (v6.1.5) software. The various predatory starfish species were combined into a starfish category, and the categories of sand were combined into a single group.

Analyses were conducted on the complete catch composition, and also on live animal (with and without scallops) and substrate subcomponents. The standardised catch of each tow was root transformed (to reduce the influence of the most dominant components), and a Bray Curtis similarity matrix was calculated. The more extreme transformation to presence/absence was also examined.

For each data set, a nested ANOSIM (strata within substrate) was initially examined to investigate differences in catch composition between *a priori* defined groups. The SIMPROF test was then used to identify significant groupings within the dendrogram calculated from the Bray Curtis similarity matrix.

Complete catch (root transformed)

Multi-dimensional scaling (MDS) plots of the root transformed catch composition data are shown in Figure 15, with symbols representing strata (upper plot) and substrate (lower plot). An ANOSIM test confirmed the visual impression that while there were significant differences between some strata, there was no significant difference between the catch compositions of mud and sand substrate habitats, as defined in the survey.



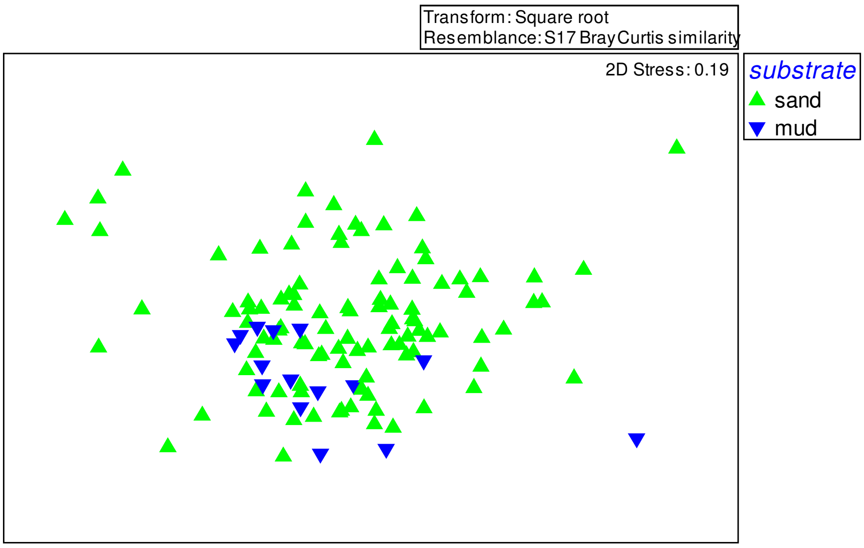


Figure 15: MDS plot of root transformed catch abundance for complete scallop survey catch. Symbols represent strata (top plot) and substrate (bottom plot), as defined in survey.

Applying the SIMPROF test (
Figure 16) divided the survey stations into 16 groups, with between 1 and 24 stations allocated to each. The catch composition of each of these groups is provided in Table 13, with the allocation by stratum indicated in Table 14. Some groups appeared unique in their catch composition (e.g., group a – dominated by live and dead *Tawera spissa*, and group f – live horse mussel), while others were very similar (e.g., groups g, i, and j, dominated by live scallops), but were discriminated by overall catch volume. Boxplots of station depth by bycatch grouping are shown in Figure 17 (top left). There is clearly some discrimination between groupings by depth, with groups b – e including stations generally deeper than elsewhere.

Complete catch (presence/absence)

When the full catch composition was transformed to presence/absence data, and the same analytical approaches applied, five groups were identified by the SIMPROF test. Most stations (110) were allocated to group e (about 30% live scallops and 30% scallop shell), with group c (similar contribution from scallops and scallop shell, but also more starfish) having five stations, and the other three groups including one station each (Table 15). Group e stations were allocated across all strata.

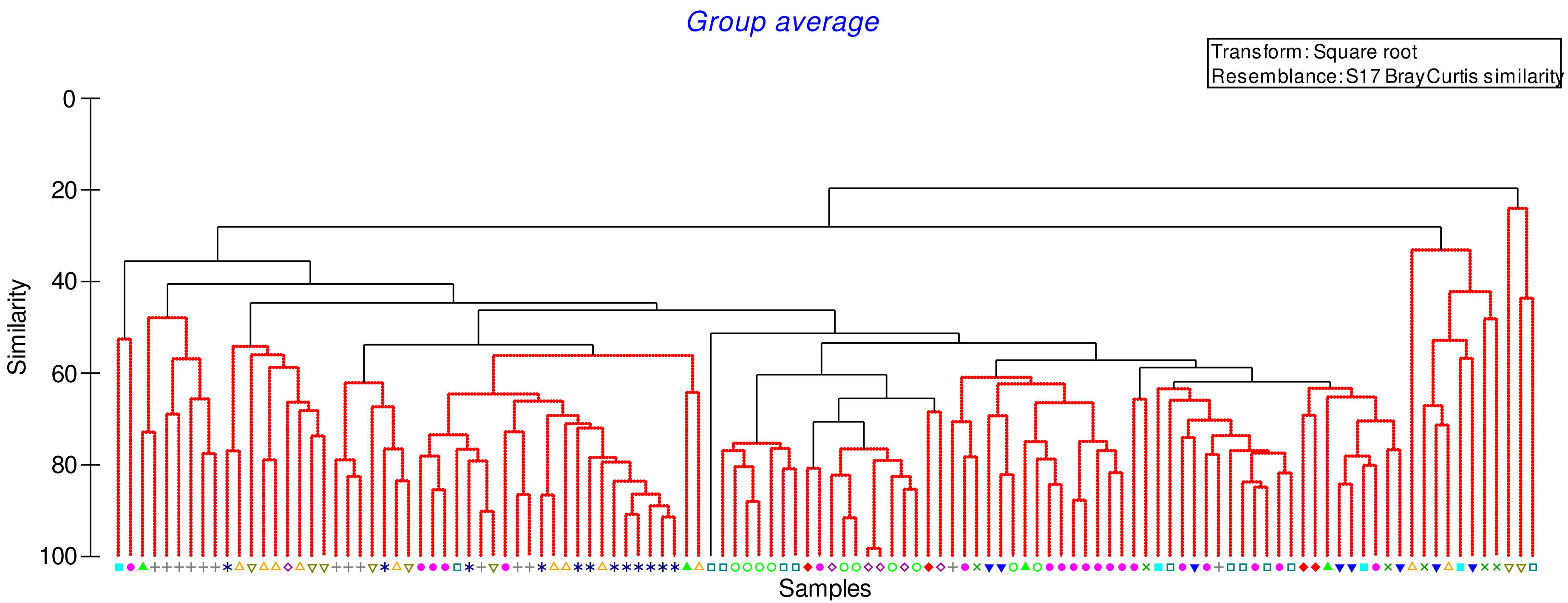


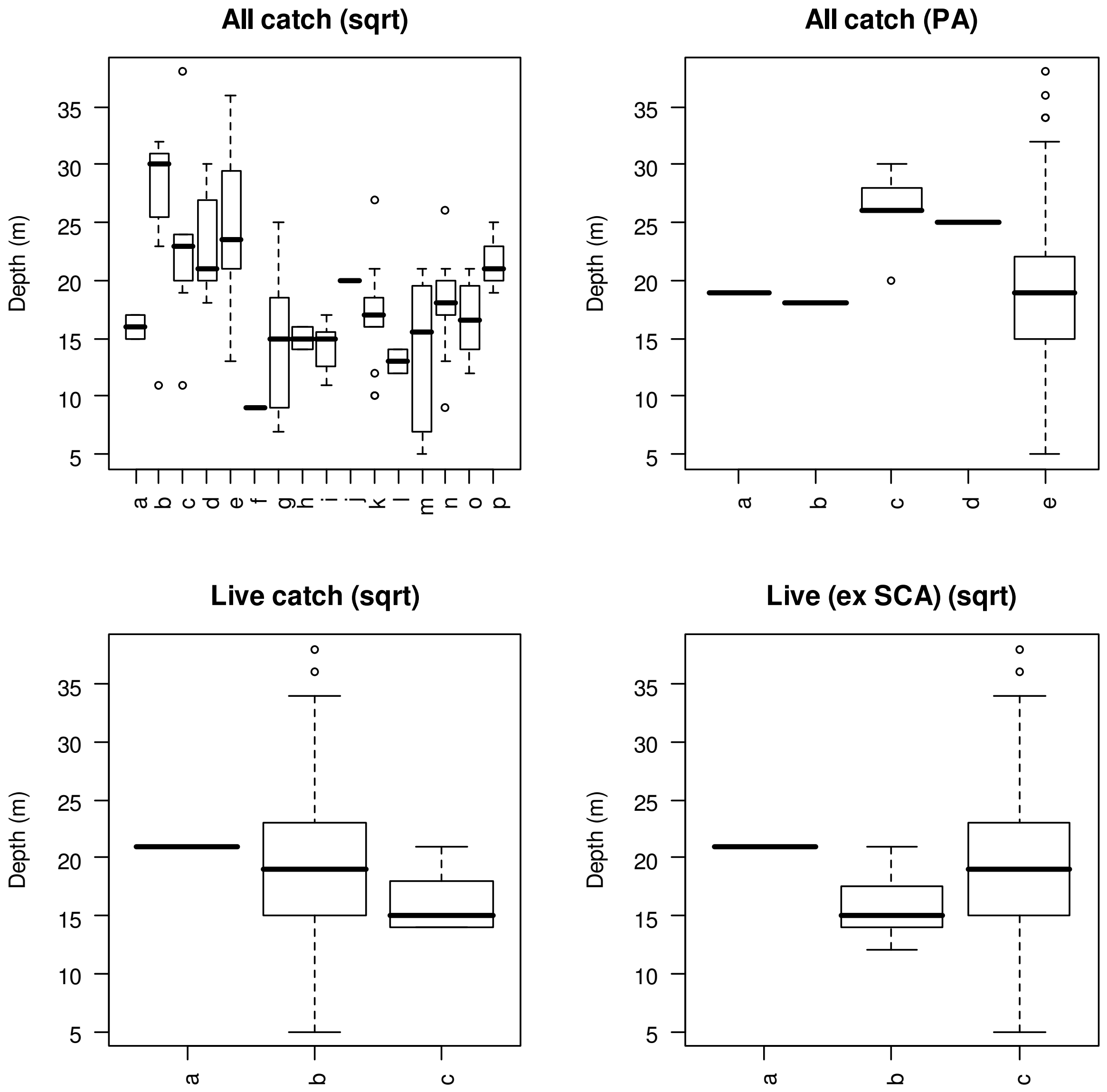
Figure 16: Dendrogram groupings from SIMPROF test. Symbols represent strata, as in Figure 15 (upper plot).

Table 13: Catch composition of catch community groups identified from SIMPROF test of root transformed catch abundance for complete scallop survey catch.

Component																Group
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Starfish	5	40	3	8	8	3	2	3	5	10	10	5	2	4	2	32
Coralline turf	1	0	0	0	0	0	0	0	0	0	1	0	0	2	7	0
Crabs	0	2	0	0	1	1	0	0	0	0	1	1	0	0	0	2
Dog cockles (L)	0	1	0	0	1	0	1	0	0	0	1	0	0	1	19	0
Horse mussels (L)	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0
Scallops (L)	13	9	1	14	19	34	82	74	86	80	35	19	24	23	2	7
Snails	1	2	0	0	1	1	0	1	0	0	1	0	1	0	0	6
Sponge (unspec)	0	3	1	2	1	0	0	1	0	0	0	0	1	0	0	7
Tawera shells (L)	10	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0
Worm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Green seaweed	0	1	0	0	0	0	0	1	0	3	0	1	0	2	0	0
Red seaweed	0	5	0	1	0	0	0	1	0	0	6	1	0	2	1	2
Dog cockles (D)	0	11	1	1	1	0	0	2	0	0	8	2	2	4	28	0
Other dead shell	7	2	13	4	4	6	2	1	1	1	11	5	6	6	3	3
Scallops (D)	10	15	24	63	57	11	6	16	4	4	20	17	36	21	2	14
Shell hash	0	6	13	1	1	0	3	0	1	0	2	22	8	31	20	0
Tawera shells (D)	45	0	1	0	2	0	0	0	0	0	2	14	1	1	7	0
Mud	0	1	4	0	0	11	0	0	0	0	0	2	0	1	0	9
Rock	0	0	25	4	4	0	0	0	1	0	0	0	2	0	1	16
Sand	8	3	13	0	0	0	2	0	1	1	2	10	17	2	4	0
No. of stations	2	7	9	7	24	1	7	2	8	2	15	2	12	9	8	3

Table 14: Numbers of stations within each stratum allocated to the catch community groups described in Table 13.

Stratum																	Group
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	Total
LITBARSTH							4		4		2						10
LITBARWST			1						4	1							6
COLVILLE					1	1	3						5			1	11
KENNEDY		6		3	3						1		1				14
BJACKS	1				4			1			8	1	4	1			20
SARAHS											1	1		1	3		6
3MB											2		1	3	2		8
MERCCV								1		1				2			4
BUMPER	1												1	1	1		4
OPITO		1			1						1			1			4
WAIHI			1	1	10												12
KNOLL			4	1	4										2		11
PAPAMOA			3	2	1											2	8
Total	2	7	9	7	24	1	7	2	8	2	15	2	12	9	8	3	118


All catch (sqrt)

All catch (PA)

Live catch (sqrt)

Live (ex SCA) (sqrt)

Figure 17: Boxplots of station depth by bycatch group.

There was some evidence of discrimination by depth of the groupings from the full catch composition presence/absence data, with group c generally deeper than group e.

Table 15: Catch composition of catch community groups identified from SIMPROF test of presence/absence transformed catch abundance for complete scallop survey catch.

Component	Group				
	a	b	c	d	e
Starfish	53	0	24	35	7
Coralline turf	0	0	0	0	1
Crabs	0	0	0	6	1
Dog cockles (L)	0	50	0	0	1
Scallops (L)	0	0	29	12	29
Snails	5	0	0	12	1
Sponge (unspec)	21	0	3	0	1
Tawera shells (L)	0	0	0	0	1
Worm	0	0	0	6	0
Green seaweed	0	0	1	0	0
Red seaweed	0	0	1	6	1
Dog cockles (D)	0	30	0	0	5
Other dead shell	0	1	4	0	6
Scallops (D)	0	0	31	6	28
Shell hash	0	15	6	0	7
Tawera shells (D)	0	2	0	0	3
Mud	21	0	1	6	1
Rock	0	0	0	12	4
Sand	0	1	0	0	4
Number of stations	1	1	5	1	110

Table 16: Numbers of stations within each stratum allocated to the catch community groups described in Table 15.

Stratum						Group
	a	b	c	d	e	Total
LITBARSTH					10	10
LITBARWST					6	6
COLVILLE	1				10	11
KENNEDY			3		11	14
BJACKS					20	20
SARAHS					6	6
3MB					8	8
MERCCV			2		2	4
BUMPER					4	4
OPITO					4	4
WAIHI					12	12
KNOLL		1			10	11
PAPAMOA				1	7	8
Total	1	1	5	1	110	118

Live component of catch (root transformed)

Examining only the live component of the catch, the SIMPROF analysis of the root transformed catch composition identified only three groups within the data, and this was reduced to only one group with a presence/absence transformation of the abundances. Catch composition for the three groups identified from the root transformed abundance of the live component of the catch is shown in Table 17. Discrimination between groups a and b was on the basis of scallop abundance (being greater in group b), while dog cockle abundance separated group c from the others. There was little distinction between the groups by depth (Figure 17, bottom left). Station allocations to groups across strata ate shown in Table 18.

Table 17: Catch composition of catch community groups identified from SIMPROF test of root transformed catch abundance for live component of the scallop survey catch.

Component	Group		
	a	b	c
Starfish	9	9	1
Coralline turf	0	0	11
Crabs	0	1	0
Dog cockles (L)	0	1	26
Scallops (L)	9	30	3
Snails	0	1	0
Sponge (unspec)	0	1	0
Tawera shells (L)	0	1	0
Red seaweed	0	2	0
Dog cockles (D)	0	4	26
Other dead shell	9	6	3
Scallops (D)	36	29	2
Shell hash	0	6	20
Tawera shells (D)	0	2	1
Mud	0	1	0
Rock	36	4	0
Sand	0	4	5
No. of stations	1	112	5

Table 18: Numbers of stations within each stratum allocated to the catch community groups described in Table 17.

strata				Group
	a	b	c	Total
LITBARSTH		10		10
LITBARWST		6		6
COLVILLE		11		11
KENNEDY		14		14
BJACKS		20		20
SARAHS		4	2	6
3MB		7	1	8
MERCCV		4		4
BUMPER		3	1	4
OPITO		4		4
WAIHI		12		12
KNOLL		10	1	11
PAPAMOA	1	7		8
Total	1	112	5	118

Live component of catch excluding scallops (root transformed)

Examining only the live component of the catch excluding scallops, the SIMPROF analysis of the root transformed catch composition identified only three groups within the data, and this was reduced to only one group with a presence/absence transformation of the abundances. Discrimination between the groups was largely on the basis of the abundance of dog cockles, starfish, and coralline turf. There was little distinction between the groups by depth (Figure 17, bottom right). Station allocations to groups across strata ate shown in Table 20.

Table 19: Catch composition of catch community groups identified from SIMPROF test of root transformed catch abundance for live component of the scallop survey catch.

Component			Group
	a	b	c
Starfish	9	2	9
Coralline turf	0	9	0
Crabs	0	0	1
Dog cockles (L)	0	18	1
Scallops (L)	9	3	30
Snails	0	0	1
Sponge (unspec)	0	0	1
Tawera shells (L)	0	7	0
Red seaweed	0	0	2
Dog cockles (D)	0	20	4
Other dead shell	9	4	6
Scallops (D)	36	3	29
Shell hash	0	15	6
Tawera shells (D)	0	14	2
Mud	0	0	1
Rock	36	0	4
Sand	0	4	4
Number of stations	1	7	110

Table 20: Numbers of stations within each stratum allocated to the catch community groups described in Table 19.

strata				Group
	a	b	c	Total
LITBARSTH			10	10
LITBARWST			6	6
COLVILLE			11	11
KENNEDY			14	14
BJACKS			20	20
SARAHS		3	3	6
3MB		1	7	8
MERCCV			4	4
BUMPER		2	2	4
OPITO			4	4
WAIHI			12	12
KNOLL		1	10	11
PAPAMOA	1		7	8
Total	1	7	110	118

5.4 Summary of bycatch analysis

The catch from each station sampled during the survey was described by estimating the volume of the various components present. This was considered a cost efficient approach to generating data on catch composition by broad categories, but would not be appropriate for finer scale biodiversity type studies. All the areas sampled were within recognised scallop grounds, and, as might be expected, scallops made up the largest component of the live material retained in dredges, although assorted shell material made up almost half (45%) of catches overall.

Multivariate analysis of the catch compositions identified distinct groups within the data, with the number of groups identified depending on the catch components included in the analysis, and the data transformation applied. There was some evidence that catch compositions were influenced by depth. Preliminary examination of the complete catch (root transformed) groupings in relation to the habitat map generated by Tuck et al (2006) identified some correlation, although over a third of the stations were not covered by the habitat map, and maps generated using more recently developed approaches may be more useful.

6. ACKNOWLEDGMENTS

This work was funded by the Ministry of Fisheries through project SCA2007/01B. Thanks to skipper Karl Aislabie and his crew of *Kataraina* for their invaluable help and experience in conducting the dredge survey, and to Peter Sopp and other members of the Coromandel Scallop Fishermen's Association for their assistance with survey design and planning. Thanks to members of the MFish Shellfish Fisheries Assessment Working Group for their appraisal of the survey and assessment methodology, and to Mike Beardsell for editorial comments.

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Appendix 1: Stratum definitions and station (tow) allocations, Coromandel scallop survey 2009. After detailed consultation with fishers, only areas expected to contain commercial densities of scallops and be amenable to fishing were included. Areas closed to commercial fishing were excluded.

Location	Stratum name	Code	Area (m^2)	Substrate	# stations	Stations/km^2
Little Barrier Island	Little Barrier West	18	1 361 542	sand	6	4.41
	Little Barrier South	19	2 802 673	sand	10	3.57
Colville	Colville South (shallow)	31	7 634 644	mud/silt	11	1.44
Mercury Islands	Mercury Cove	4	2 840 945	mud/silt	4	1.41
	Three Mile Bank	2	4 924 946	sand	8	1.62
	Bumper Cove	43	1 210 602	sand	4	3.30
	Kennedy	41	28 523 438	sand	14	0.49
	Blackjack	1	28 298 340	sand	20	0.71
	Sarah's Gully	42	5 186 157	sand	6	1.16
	Opito Bay	3	1 896 500	sand	4	2.11
Bay of Plenty	Waihi (Katikati entrance)	11	47 210 938	sand	12	0.25
	Papamoa Beach	14	4 505 615	sand	8	1.78
	Motiti (The Knoll)	13	7 580 078	sand	11	1.45
Total	13 strata	–	143 976 418	–	118	0.82