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Abundance of scallops (*Pecten novaezelandiae*) in Coromandel recreational fishing areas, 2009 and 2010

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Diver surveys of scallops were conducted in 2009 and 2010 at two recreational fishing locations within the Coromandel scallop stock (SCA CS). Two strata were surveyed per location. Survey locations and strata were determined in 2006 after consultation with the Ministry of Fisheries and commercial and recreational fisheries stakeholders. Stratum boundaries were modified slightly in 2009 to better reflect the extent of the scallop bed (target population) at each site. The revised stratum boundaries excluded areas of the seabed that the 2006–08 surveys had shown were unsuitable habitats for scallops (i.e., too shallow, patch reef). The revised strata used in 2009 were used again in 2010. Density and biomass estimates were made assuming 100% diver efficiency, and thus were treated as absolute estimates.

The abundance and size structure of scallops varied markedly among the areas surveyed. At the time of the 2009 survey (July), absolute recruited biomass of scallops over 100 mm shell length (the recreational minimum legal size) for the selected Coromandel strata surveyed (with a combined area of 3.6 km^2) was predicted to be 50.2 t greenweight or 6.4 t meatweight, with c.v.s of 13%. Current Annual Yield estimates were also made for the surveyed areas, based on $F_{0.1}$ derived from previous individual-based modelling, suggesting a meatweight yield of 3.7 t for the surveyed areas.

At the time of the 2010 survey (June), absolute recruited biomass of scallops over 100 mm shell length (the recreational minimum legal size) for the selected Coromandel strata surveyed (with a combined area of 3.6 km^2) was predicted to be 44 t greenweight with a c.v. of 13%. Current Annual Yield estimates were also made for the surveyed areas, based on $F_{0.1}$ derived from previous individual-based modelling, suggesting a meatweight yield of 3.5 t for the surveyed areas.

It is unclear how recreational landings relate to the CAY estimates for the areas surveyed, or how a CAY can be incorporated into the current recreational scallop fishery management system.

Scallop densities in areas open and closed to commercial dredging were compared using data from the annual diver and dredge surveys from 2006–10. Overall, scallop abundance in commercial and some recreational areas seems to have varied in similar ways but it is difficult to draw firm conclusions about the nature of this relationship.

1. INTRODUCTION

1.1 Overview

This report presents the results of diver surveys of scallops carried out in selected Coromandel recreational fishing areas in July 2009 and June 2010. This work was carried out under Ministry of Fisheries project SCA2008-01: Abundance of scallops in Northland and Coromandel recreational fishing areas. The overall objective of the project was to establish a relationship between scallop abundance in the main commercial scallop beds estimated each year in pre-season surveys, and scallop abundance in recreational fishing areas in the Northland and Coromandel scallop fisheries. Specific objectives were:

1. to investigate the relationship between scallop abundance in commercial and non-commercial areas in the Northland scallop fishery by undertaking a survey in about May/June 2009, 2010, and 2011, to estimate the absolute abundance and population size frequency of scallops in the recreational scallop beds (the requirement to survey the recreational beds in Northland was withdrawn by Ministry of Fisheries because there were no dredge surveys of the Northland commercial areas in those years for comparison);

2. to estimate yield following the completion of the survey described in Objective 1. (this specific objective was withdrawn by the Ministry of Fisheries);

3. to investigate the relationship between scallop abundance in commercial and non-commercial areas in the Coromandel scallop fishery by undertaking a survey in about May/June 2009, 2010, and 2011, to estimate the absolute abundance and population size frequency of scallops in the recreational scallop beds (the requirement to survey the recreational beds in Coromandel in 2011 was withdrawn by the Ministry of Fisheries because there was no dredge survey of the commercial areas in 2011 for comparison).

4. to estimate yield following the completion of the survey described in Objective 3.

Estimates of scallop abundance from diver surveys of recreational fishing areas can be compared to estimates from pre-season dredge surveys of commercial fishing areas. However, similar to the situation in 2008 and 2009, the Ministry of Fisheries did not require pre-season dredge surveys of the Northland commercial scallop fishery in 2010 or 2011, nor the Coromandel commercial scallop fishery in 2011, so the planned diver surveys of scallops in recreational fishing areas (specific objectives 1 and 2) were withdrawn. This report is the last of the 2006–10 series of diver surveys in the Northland and Coromandel recreational fishing areas.

1.2 Northern scallop fisheries

Scallops (*Pecten novaezelandiae*) support regionally important commercial and non-commercial (recreational and Maori customary) fisheries off the northeast coast of New Zealand’s North Island. Both the Coromandel (SCA CS) and Northland (SCA 1) scallop 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). All commercial fishing is by dredge, and is undertaken within discrete beds distributed patchily around the coastline. Catch and catch rates from both fisheries are variable both within and among years (Cryer & Parkinson 2006), a characteristic of scallop fisheries worldwide (Shumway 1991).

There is a strong non-commercial interest in scallops in suitable areas throughout the Coromandel and Northland fishery areas, mostly in enclosed bays and harbours. Non-commercial 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 in the northern fisheries 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 allowed 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.

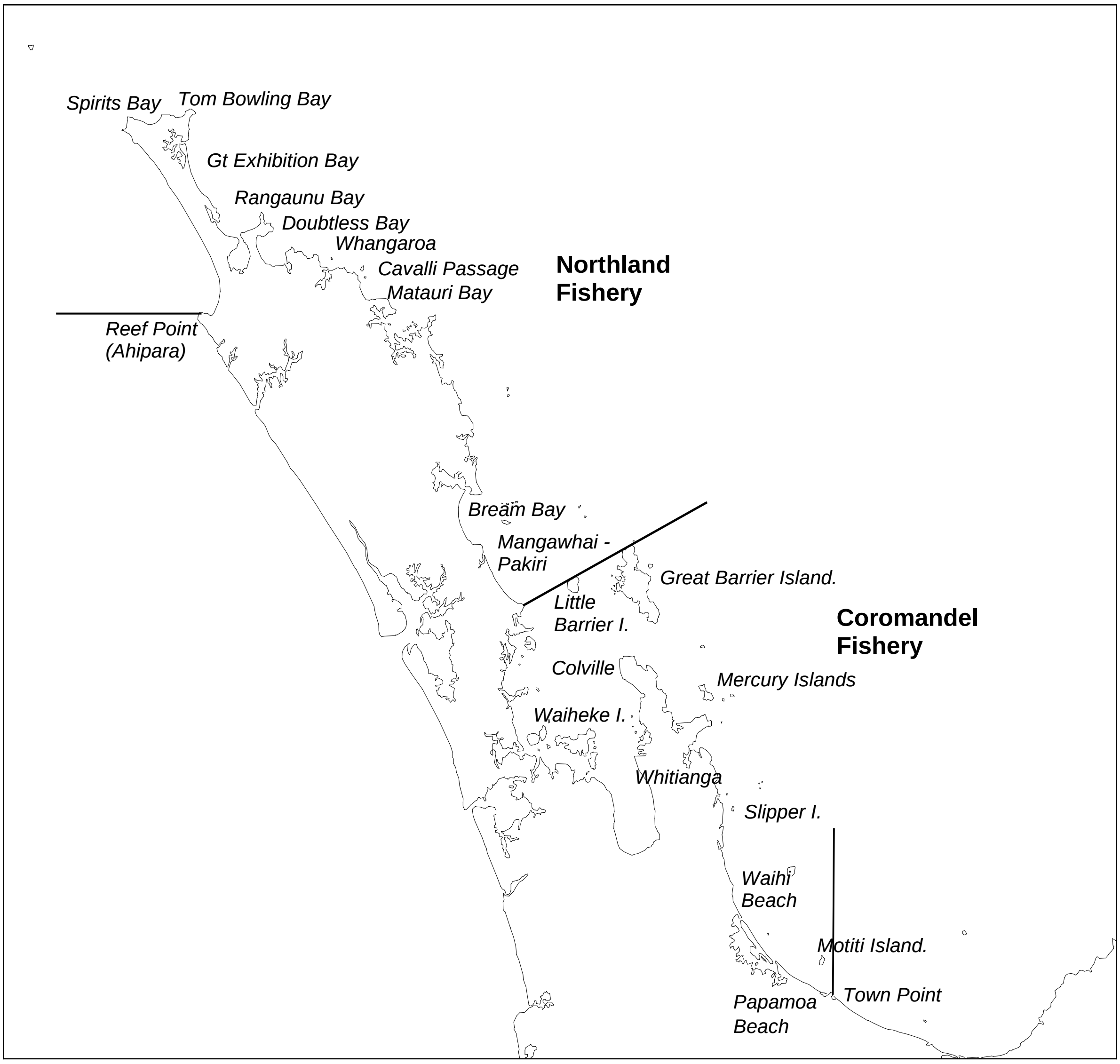

Figure 1: Geographic distribution of the two northern scallop fisheries (after Cryer & Parkinson 2006).

A pilot study was conducted in 2007–08 to assess the feasibility of estimating the recreational catch in the Coromandel scallop fishery between Cape Colville and 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 estimates of non-commercial harvest from the Coromandel or Northland scallop fisheries. Estimates of catch by recreational fishers from both fisheries have been made on four occasions as part of recreational fishing (telephone and diary) surveys (Bradford 1997, 1998, Boyd & Reilly 2002, Boyd et al. 2004). 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.”

Annual pre-season scallop surveys have been conducted in the commercial areas of each fishery for many years. These surveys provide estimates of pre-season biomass required for stock assessment (e.g., see Cryer & Parkinson 2006, Williams et al. 2007, Williams 2008, 2009a, Williams & Parkinson 2010, Williams et al. 2010). It remains unclear, however, whether the abundance of scallops in recreational areas is related in some way to changes in abundance in the commercial areas. In this study, estimates of abundance in recreational areas were required to investigate any relationship between scallop abundance in commercial and non-commercial areas. Given the life history of *Pecten novaezelandiae*, in particular the extended larval dispersal phase of about three to four weeks, it is possible that changes in the abundance of scallops in some of the commercial areas might be reflected by similar changes in abundance in the recreational areas. The strength of any relationship in abundance between scallops in areas open and closed to commercial fishing will be influenced by several factors, including population source and sink dynamics, and the degree of geographic separation between areas. If adjacent areas have similar types of habitat, and spat settlement is related to local supply, then we may expect adjacent areas to show stronger similarity in trends than areas further apart. Presently, little is known about stock structure or population connectivity for scallops, nor the relative influence of environmental conditions and fishing activities on recruitment. This lack of knowledge represents a fundamental obstacle to understanding the population dynamics of scallops.

Under the current research programme, diver surveys of scallops were conducted in 2006 (Williams et al. 2008), 2007 (Williams 2009b), and 2008 (Williams 2009c) at selected scallop beds (strata) in Northland and Coromandel recreational fishing locations (note that Northland strata were surveyed in 2006 and 2007 only). As the data became available, the length frequency distribution and estimated density of scallops from the diver surveys of recreational areas were compared to those from the annual pre-season dredge surveys of the commercial areas. Scallop abundances in some commercial and recreational areas seem to have varied in similar ways, but it was acknowledged that it was too early to draw firm conclusions about the nature of any putative relationship. A recent revision of dredge efficiency estimates (conducted under Ministry of Fisheries projects SCA200802 and SAP200913) has not been applied in these previous analyses, and this may also change perceptions of the relationships observed. More data (areas and years) were required for a thorough examination. The present study reports the results of the 2009 and 2010 diver surveys of scallops in Coromandel recreational fishing areas, marking the fourth and fifth in a 2006–11 planned series of consecutive annual surveys of these areas. The withdrawal of the 2011 recreational survey objective makes the 2010 survey the final in the series.

2. METHODS

2.1 Survey design

The 2009 and 2010 surveys of scallops in Coromandel recreational fishing areas were conducted using stratified random sampling by scuba divers. Owing to constraints on vessel time, surveys were of only single phase.

The 2009 survey was carried out from 9–10 and 27–31 July 2009. The fieldwork was originally scheduled for June 2009 but was delayed by stormy weather. The 2010 survey was conducted from 2–4 and 14–18 June 2010.

Two locations were surveyed in the Coromandel fishery: Kawau Island and the Mercury Islands. These locations were chosen to represent recreational fishing areas spatially separated from (Kawau Island) and adjacent to (Mercury Islands) commercially fished areas, thus allowing us to assess the abundance of scallops in the recreational areas in relation to their proximity to the commercially fished areas.

At each location, two areas (strata) were chosen that represented well known recreational scallop beds that have sustained persistent scallop populations over many years. The four Coromandel strata were: Bostaquet Bay and Iris Shoal (Kawau Island), and Mercury Cove and Opito Bay (Mercury Islands) (Figure 2). Survey locations and strata were originally developed and surveyed for the first time in 2006 (Williams et al. 2008) after consultation with the Ministry of Fisheries, and commercial and recreational scallop fishers. The same strata were surveyed again in 2007 (Williams 2009b) and 2008 (Williams 2009c). The strata in 2009 were modified slightly from those used in the 2006–08 surveys by redrawing the stratum boundaries to better reflect the extent of the scallop bed (target population) at each site. The revised stratum boundaries excluded areas of the seabed that the 2006–08 surveys had shown were unsuitable habitats for scallops (i.e., too shallow or patch reef). This marginally changed the areal extent of each stratum, except for Opito Bay where a significant area (the shallow surf zone, 0.7 km^2) was excluded because the previous surveys had shown that scallops were rarely found that shallow. The strata in 2010 were the same as those used in 2009.

Within each stratum, up to 26 stations were surveyed by divers using circular searches (see below). The allocation of stations was constrained by operational requirements such as steaming time between strata, the NIWA Code of Scientific Diving Practice and the requirement of a minimum of 12 stations per stratum. The positions of stations within strata were randomised using computer software, which constrained the positions to keep all stations at least 20 m apart. This software estimated the area of each stratum, and allocated the latitude and longitude of each random station.

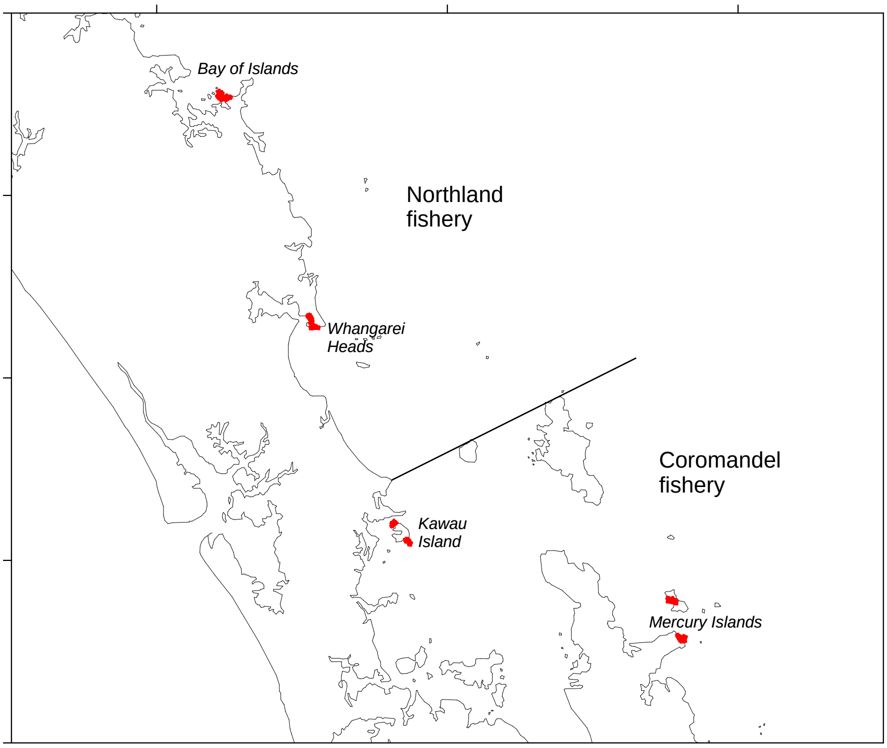

Figure 2: Location of sampling strata for the diver surveys of Northland and Coromandel recreational fishing areas, 2006–10 (see Appendix 1 for stratum details). Northland strata were not surveyed in 2008, 2009, or 2010.

2.2 Diver sampling

Diver surveys were carried out from the vessel *Hawere* (University of Auckland's Leigh Marine Laboratory, Leigh) and the charter vessel *Whai* (Marine Adventures Ltd, Whitianga). For each trip, the vessel was navigated to each station in turn by use of a combined Global Positioning System (GPS) and marine plotter. The following sampling methodology was based on that used during the 2006–08 surveys (Williams et al. 2008, Williams 2009b, c).

At each station, a buoyed shot line was deployed to mark the centre of the search pattern on the seabed. Two divers descended the shot line to the seabed to begin a circular search sweep for scallops. On reaching the seabed, the lead diver attached to the shot line a sweep rope of 8 m total length marked 3 m from its free end. The search area for each station was defined by the area traversed by the sweep rope, and three alternative search areas were, therefore, available: 1) a circle of radius 8 m (201.05 m^2); 2) a circle of radius 5 m (78.54 m^2); or 3) a "doughnut" comprising the 8 m circle minus the 5 m circle (122.52 m^2).

On approaching the seabed during the descent, 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 20 or more near-legal sized scallops, then the smaller search circle was selected. Alternatively, the larger circle was used. This method of divers deciding whether to conduct an 8-m or 5-m radius circular search at a given station introduces a bias, which was examined in section 3.3. Note that such a bias was not present in 2010 because all circular searches were *a priori* of 5-m radius, except in Opito Bay where all searches were 8-m radius. The divers progressed to the end of the sweep rope and positioned themselves about 1 m apart. The start position for the search was marked using a small subsurface marker buoy attached to a lead weight. The divers swam a complete circuit of the search pattern while maintaining the sweep rope taut. All scallops passing under the sweep rope were collected by hand and placed in zippered or spring-loaded catch bags. If the larger circle was searched, then only scallops falling outside the 3 m mark were collected on the first circuit. On 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 line and continued the search. The search ended on completion of the chosen circle, or if 20 or more near-legal sized scallops had been collected from the outer ring of the 8 m circle, or if the divers were within 3 minutes of their maximum no-decompression limits.

On completion of the circular search, the divers removed the sweep rope from the shot line and returned to the boat with the bags of scallops. All scallops were measured for shell length (maximum dimension parallel with the shell hinge) to the next whole millimetre down using electronic callipers (mounted on a measuring board) interfaced to a portable, handheld computer (Allegro). These measurements were recorded together with the date, location, stratum, station number, search area, water depth, substratum type, and any other relevant observations. The efficiency of diver searches was assumed to be 100%.

In some previous diver surveys (both within this recent series, and also as part of the commercial area surveys during the 1980s and 1990s), the decision to search a 5 m or a 8 m radius area has been taken by the divers upon reaching the seabed, to try to avoid "zero scallop" searches. This approach introduces a positive bias (increasing mean density), and is also likely to reduce the variance of the estimate. It was originally planned to investigate the extent of this effect in the 2011 survey, but the withdrawal of this survey prevented this. The extent of this bias was investigated (see Section 3.3) by reanalysing the 2006–09 Coromandel survey data assuming that all searches with an 8-m radius contained zero scallops, rather than the actual number recorded (the Northland 2006 and 2007 estimates were not recalculated but are expected to have a similar level of bias to the Coromandel estimates).

2.3 Density and length frequency estimation

Counts of scallops of any given size at each station were converted to numbers per square metre of seabed (i.e., scallop density) according to the area swept by divers. The mean scallop density and its associated variance were calculated for each stratum and for groups of strata using standard parametric methods (Snedecor & Cochran 1980) as follows.

The sample mean for stratum *h* is calculated as

$$\bar{x}_h = \frac{\sum_{i=1}^{n_h} x_{hi}}{n_h}$$

where *i* denotes the sampling unit (circular search) within the stratum, x_{hi} is the value (density of scallops) for the *i*th unit within stratum *h*, and n_h is the sample size (number of stations where circular searches were conducted within stratum *h*).

The sample variance for stratum *h* is calculated as

$$s_h^2 = \frac{\sum_{i=1}^{n_h} \left(x_{hi} - \bar{x}_h\right)^2}{n_h - 1}$$

To combine all strata and estimate the overall mean density of the population, the stratified estimator is

$$\bar{x} = \sum_{h=1}^{L} W_h \bar{x}_h$$

where W_h is the relative weight attached to stratum h (where $W_h = N_h/N$, with N_h being the area in m^2 of stratum h, and N being the sum total area of all strata), $\bar{x}_h$ is the sample mean for stratum h, and L is the number of strata.

The variance estimator is

$$\text{var}(\bar{x}) = \sum_{h=1}^{L} W_h^2 \frac{s_h^{\ 2}}{n_h}$$

No finite correction term was applied because the sampling fraction was negligible (Snedecor & Cochran 1980).

For stratified random sampling, the sample mean and variance are unbiased estimates of the population mean and variance. The overall estimated population abundance, X, is simply

$$X = \bar{x}N$$

The coefficient of variation for the overall population is

$$c.v. = \frac{\sqrt{\text{var}(\bar{x})}}{\bar{x}}$$

One output statistic from this work, therefore, was the mean density (and variance) of legal sized scallops (or other size range of interest) per square metre of seabed. This statistic was compared with the mean density of scallops in the Coromandel commercial fishery areas estimated from NIWA's dredge surveys (Williams et al. 2010). Estimates of commercial scallop densities were corrected for dredge efficiency using new efficiency estimates produced in April 2011 from preliminary parametric modelling (Ministry of Fisheries projects SCA200802 and SAP200913).

Station length frequency distributions were estimated by scaling the recorded length frequency distributions to a square metre of seabed. Stratum length frequency distributions were estimated as the mean station length frequency distribution for that stratum scaled by the stratum area (m^2). Length frequency distributions for any particular combination of strata were derived by the addition of stratum length frequency distributions.

2.4 Biomass and yield estimation

During the data analysis phase of the 2006 recreational scallop survey project (Williams et al. 2008), and additional to the original objectives of the study, the Ministry of Fisheries requested that estimates of scallop biomass and yield were made for the recreational areas surveyed. Such estimates have been a requirement for all subsequent recreational scallop survey projects. To provide estimates of yield, we used a reference rate of fishing mortality (F) from an individual-based model analysis of the Coromandel commercial fishery (Cryer & Morrison 1997a). This approach was not strictly correct, because the reference F used was calculated over a shorter period (5 months) than the recreational fishery (7 months); however, this difference is unlikely to be important relative to the other uncertainties in the process of estimating biomass and yield. Yield estimation from recreational fisheries in future studies could be improved by using a revised analysis of the individual-based model (Cryer & Morrison 1997a) for a recreational fishery, but that was not required for the present study.

The method of estimating biomass was based on that used for commercial scallop surveys (Cryer & Parkinson 2006), and contains the following eight 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 density per unit area of seabed, i.e., assuming the divers to be 100% efficient for all size classes. These are combined to estimate the population length frequency distribution.

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

4. 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.

5. 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.

6. The population length frequency distribution (from step 2) 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.

7. 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.

8. 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.

Yield estimates are generally calculated using reference rates of fishing mortality applied in some way to an estimate of current or reference biomass. However, the choice among reference rates is not simple. As with the approach taken with the Coromandel and Northland commercial scallop stock assessments, Caddy’s (1998) notation of target reference points (TRP) and limit reference points (LRP) was used, where reference points can be measures of fishing mortality (F) or biomass (B).

No reference F values are available for recreational fisheries, but, as a first estimate, values have been taken from commercial fisheries. Cryer & Morrison’s (1997a) study of the incidental effects of scallop dredges in the Coromandel fishery allowed the estimation of F_{max} as an LRP, and $F_{0.1}$ and $F_{40\%}$ as TRPs. Although their study specifically investigated the effects of a dredge fishery, an appropriate scenario for a recreational scallop fishery could be provided by selecting simulations with knife-edge selection at 100 mm, no incidental effects on growth or mortality, and a natural mortality of $M = 0.5$ (although based on a 5 month rather than 7 month fishing season). Making no allowance for incidental effects on mortality and growth also assumes that all catches are taken by divers rather than by recreational dredges, which are likely to have some incidental effects. Under this simulation, $F_{0.1}$ was estimated to be 0.984 for the 5-month commercial fishery, which equates to an instantaneous rate of $F_{0.1} = 2.362$ ($5/12 * F_{0.1} = 0.984$). Current Annual Yield can be estimated 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 100 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 (on the basis of which the reference F was calculated). Preliminary investigations suggest the implications of using this commercial fishery value of F are small (M. Cryer, Ministry for Primary Industries, Wellington, pers. comm.) but reference F values for recreational fisheries should be investigated.

3. RESULTS

3.1 2009 survey

3.1.1 Scallop population at the time of survey (July 2009)

Stratified random sampling by divers was conducted at 75 valid stations in July 2009, sweeping an estimated 9783 m^2 of seabed (see Appendix 1); a total of 5713 scallops were collected and measured. Approximate length frequency distributions (scaled to estimated population size) varied considerably among strata (**Figure** 3), and when pooled by their respective locations (**Figure** 4). Figure 5 shows the length structure of the total population surveyed. Scallops of recreational legal size (100 mm or more shell length) were present in all strata sampled, but were in relatively high abundance only at Iris Shoal and Mercury Cove; all strata were dominated by scallops under legal size.

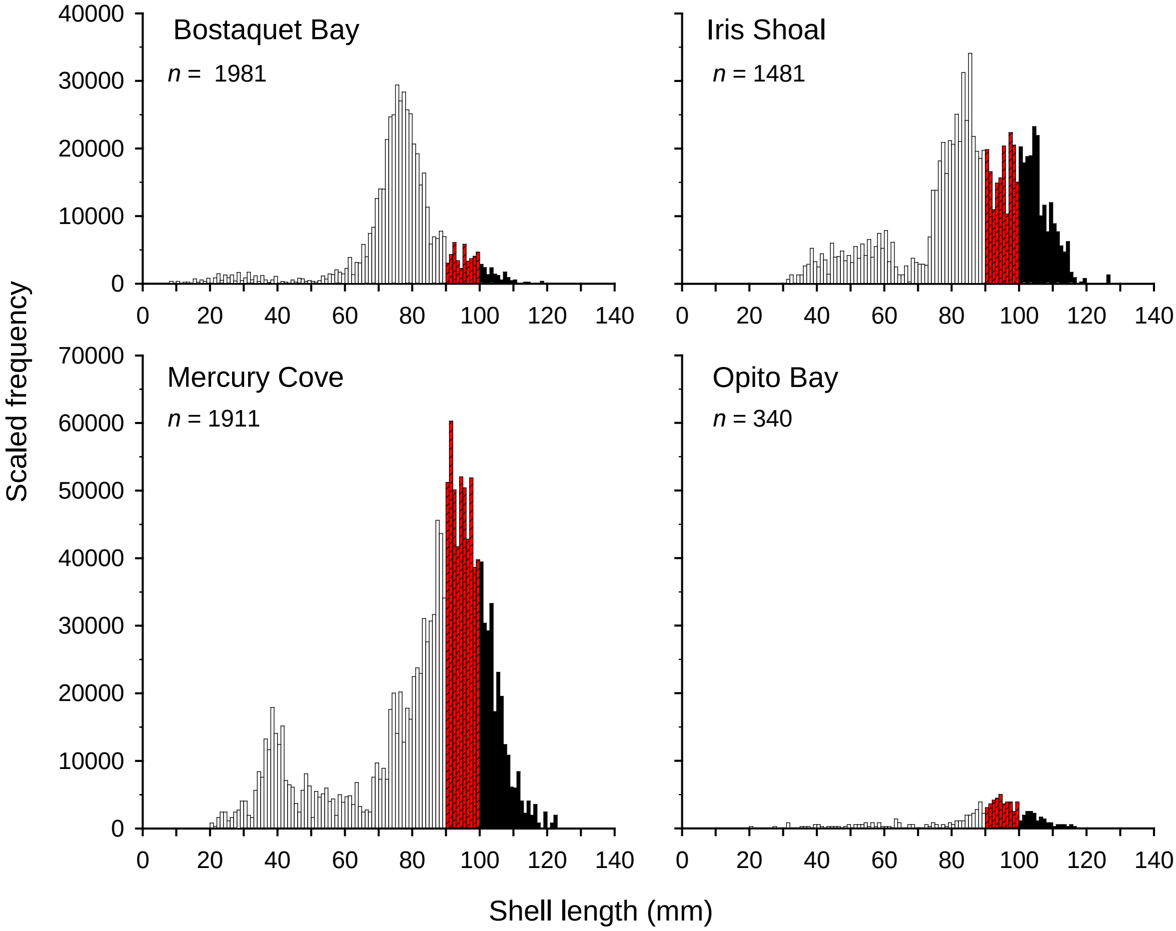

Figure 3: Length frequency distributions for the four strata surveyed during the 2009 surveys of scallops in Coromandel recreational fishing areas. Shaded bars show scallops 90 mm or more shell length and black bars show scallops 100 mm or more. n, number of scallops collected.

At the level of individual stations (circular searches), the density of scallops of any size ranged from zero to 10.45 m^{-2}, or zero to 0.78 m^{-2} for scallops of 100 mm or more shell length; these high densities were observed at Bostaquet Bay and Iris Shoal, respectively. At the stratum level, the density of scallops of legal size (100 mm or more shell length) was highest at Iris Shoal (0.30 m^{-2}), fairly high at Mercury Cove (0.17 m^{-2}), low at Bostaquet Bay (0.05 m^{-2}), and lowest at Opito Bay (0.02 m^{-2}) (**Table** 1). At the location level, the density of legal scallops was highest at Kawau (0.22 m^{-2}) and lowest at Mercury (0.11 m^{-2}), the latter the result of combining high densities at Mercury Cove with low density at Opito Bay (**Table** 1).

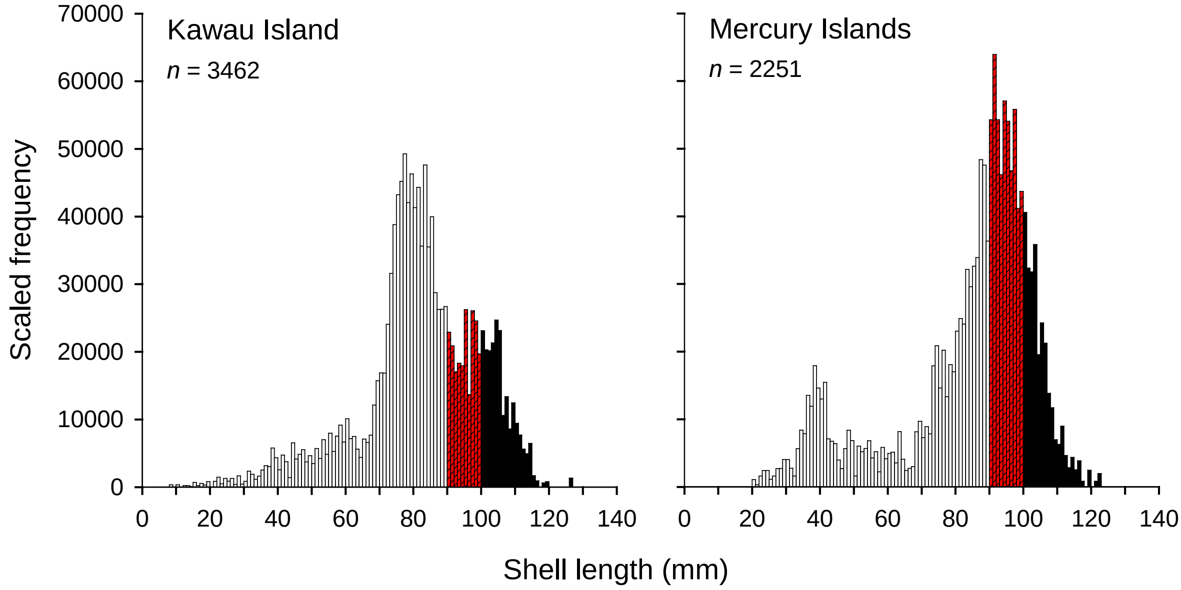

Figure 4: Length frequency distributions for the two locations surveyed during the 2009 surveys of scallops in Coromandel recreational fishing areas. Shaded bars show scallops 90 mm or more shell length and black bars show scallops 100 mm or more. n, number of scallops collected.

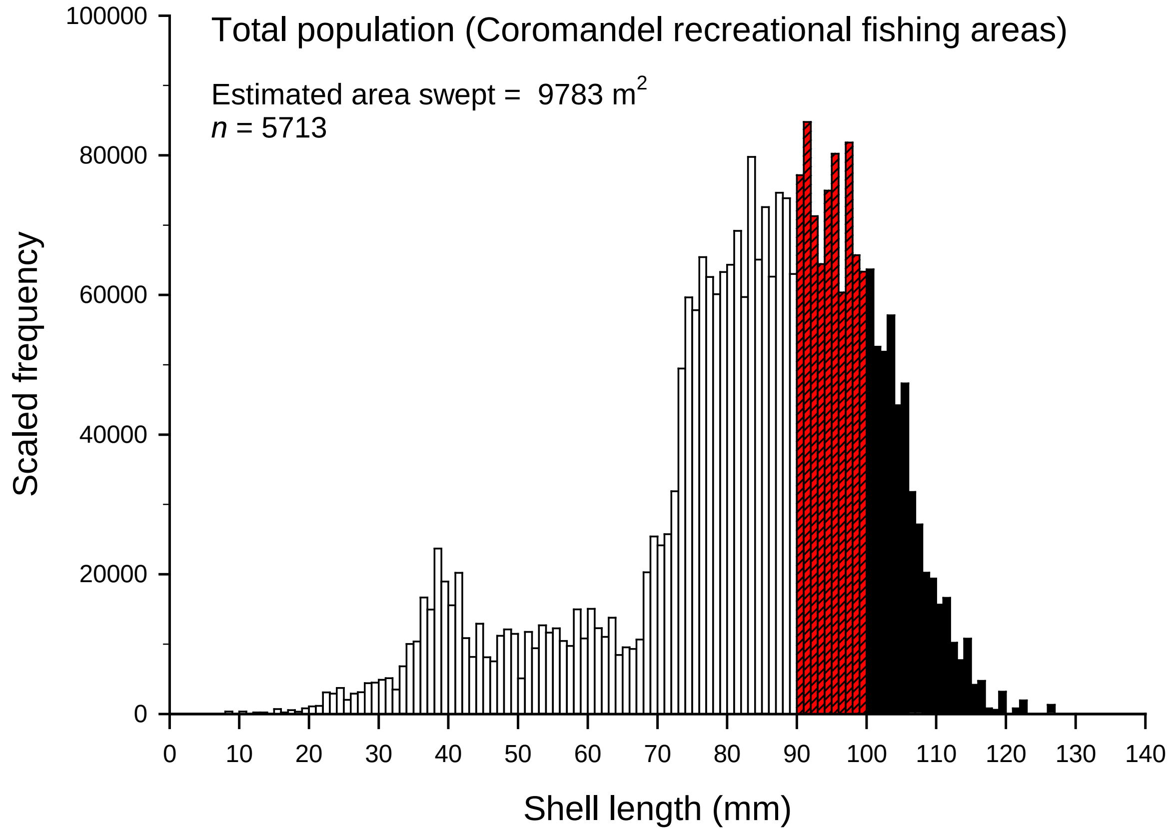

Figure 5: Length frequency distribution for the total area surveyed during the 2009 surveys of scallops in Coromandel recreational fishing areas. Shaded bars show scallops 90 mm or more shell length and black bars show scallops 100 mm or more. *n*, number of scallops collected.

Using a simple parametric approach to estimation (and assuming 100% diver efficiency), the recruited biomass of scallops (100 mm or more shell length) at the time of the survey ranged from 2 to 26 t greenweight for the individual strata surveyed, with c.v.s ranging from 17 to 33% (**Table** 1). It should be noted that the strata were of quite different sizes (range 0.33–1.52 km^2, see Appendix 1) and, to a certain extent, biomass estimates were related to stratum area. Pooling the strata into their locations, biomass estimates were 22 and 28 t for Kawau and the Mercury Islands, respectively. A resampling with replacement (bootstrapping) approach to estimation (resampling stations within strata and length-weight regressions) made very little difference to the estimates, or their uncertainty (Table 2). Estimated density and biomass of scallops 90 mm or more shell length (**Table** 3**)** and of scallops of any size (**Table** 4) are also presented below.

Table 1: Estimated density and biomass of scallops 100 mm or more shell length at the time of the 2009 surveys (using a simple parametric approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass ($g\ m^{-2}$)	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	19	0.0493	0.0158	0.32	0.016	98.90	4.88	1.60	0.33	1.63
Iris Shoal	0.67	13	0.3010	0.0659	0.22	0.201	103.01	31.01	6.84	0.22	20.71
Mercury Cove	1.52	24	0.1692	0.0281	0.17	0.258	100.49	17.00	2.81	0.17	25.90
Opito Bay	1.06	19	0.0181	0.01	0.30	0.019	102.06	1.84	0.55	0.30	1.96
Kawau	1.00	32	0.2170	0.0442	0.20	0.218	102.70	22.29	4.59	0.21	22.34
Mercury	2.59	43	0.1070	0.0167	0.16	0.277	100.60	10.77	1.67	0.16	27.87
Total	3.59	75	0.1377	0.0172	0.13	0.495	101.52	13.98	1.76	0.13	50.21

Table 2: Estimated density and biomass of scallops 100 mm or more shell length at the time of the 2009 surveys (using a resampling with replacement approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass ($g\ m^{-2}$)	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	19	0.0497	0.0151	0.30	0.017	99.58	4.95	1.53	0.31	1.65
Iris Shoal	0.67	13	0.3040	0.0645	0.21	0.203	103.69	31.52	6.74	0.21	21.05
Mercury Cove	1.52	24	0.1681	0.0284	0.17	0.256	101.10	17.00	2.86	0.17	25.91
Opito Bay	1.06	19	0.0181	0.0055	0.30	0.019	102.76	1.86	0.56	0.30	1.98
Kawau	1.00	32	0.2191	0.0432	0.20	0.220	103.38	22.65	4.51	0.20	22.71
Mercury	2.59	43	0.1065	0.0169	0.16	0.276	101.22	10.78	1.70	0.16	27.89
Total	3.59	75	0.1379	0.0173	0.13	0.495	102.18	14.09	1.77	0.13	50.59

Table 3: Estimated density and biomass of scallops 90 mm or more shell length at the time of the 2009 surveys (using a simple parametric approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass ($g\ m^{-2}$)	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	19	0.1708	0.0490	0.29	0.057	82.78	14.14	4.13	0.29	4.73
Iris Shoal	0.67	13	0.5503	0.1185	0.22	0.368	90.92	50.04	10.62	0.21	33.42
Mercury Cove	1.52	24	0.4833	0.0802	0.17	0.737	84.28	40.74	6.67	0.16	62.08
Opito Bay	1.06	19	0.0539	0.01	0.26	0.057	84.71	4.57	1.20	0.26	4.86
Kawau	1.00	32	0.4237	0.0807	0.19	0.425	89.83	38.06	7.21	0.19	38.15
Mercury	2.59	43	0.3068	0.0476	0.16	0.794	84.31	25.87	3.96	0.15	66.94
Total	3.59	75	0.3394	0.041	0.12	1.219	86.24	29.27	3.49	0.12	105.09

Table 4: Estimated density and biomass of scallops 1 mm or more shell length at the time of the 2009 surveys (using a simple parametric approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass ($g\ m^{-2}$)	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	19	1.4801	0.5572	0.38	0.495	45.33	67.09	25.59	0.38	22.43
Iris Shoal	0.67	13	1.2924	0.3336	0.26	0.863	62.54	80.82	19.21	0.24	53.98
Mercury Cove	1.52	24	0.9589	0.1469	0.15	1.461	61.06	58.55	9.08	0.16	89.23
Opito Bay	1.06	19	0.0890	0.0209	0.23	0.095	67.22	5.98	1.56	0.26	6.37
Kawau	1.00	32	1.3550	0.2898	0.21	1.358	56.27	76.24	15.39	0.20	76.41
Mercury	2.59	43	0.6012	0.0869	0.14	1.556	61.44	36.94	5.38	0.15	95.59
Total	3.59	75	0.8116	0.1023	0.13	2.914	59.03	47.91	5.79	0.12	172.00

3.1.2 Scallop population at the start of the 2009 commercial season

In similar previous surveys (Williams et al. 2008, Williams 2009b, c), biomass at 15 July (the nominal start of the commercial fishing season) was estimated (‘projected’) from the time of survey biomass by allowing for growth and assumed natural mortality (M = 0.5, spread evenly through the year) using a resampling with replacement (bootstrapping) approach to estimation (resampling stations within strata, length-weight regressions, and growth). In 2009, however, the timing of the recreational scallop surveys (9–10 and 27–31 July) coincided with the start of the commercial scallop season (15 July), so estimates of projected biomass were unnecessary. Estimates of start of season (15 July) greenweight biomass (Table 2) can be converted to estimates of meatweight biomass using historical annual average meatweight recovery data (see Appendix 2). This resulted in an overall estimate of 6.4 t meatweight with a c.v. of 17% at the start of the Coromandel scallop commercial start of season.

3.1.3 2009 yield estimates

Current Annual Yield (CAY) estimates were provided for each of the recreational areas surveyed using the 2009 biomass estimates (Table 2) from the time of survey (mid July, which coincided with the start of the commercial fishing season, 15 July). Estimates of biomass in greenweight were converted to estimates in meatweight by assuming average annual recovery of meatweight from greenweight. The estimates of start of season biomass and the reference fishing mortality rate $F_{0.1}$ = 2.3616 yr^{-1} (previously reported as 0.984 for the 5 month duration of the commercial fishing season) were used to calculate CAY for the areas surveyed (Table 5). These estimates of CAY would have a c.v. at least as large as that of the estimates of start of season biomass, are sensitive to assumptions about recovery of meatweight from greenweight, and relate to the surveyed beds only.

Table 5: Estimates of Current Annual Yield (scallops 100 mm shell length or more) for the Coromandel recreational fishing areas surveyed in July 2009. CAY values were calculated using the Baranov catch equation and the reference fishing mortality rate $F_{0.1}$ (2.3616 yr^{-1}).

Stratum/Location	Area (km^2)	Biomass (t green)	Biomass (t meat)	CAY (t green)	CAY (t meat)
Bostaquet Bay	0.33	1.6	0.2	0.9	0.1
Iris Shoal	0.67	20.7	2.6	11.9	1.5
Mercury Cove	1.52	25.9	3.3	14.9	1.9
Opito Bay	1.06	2.0	0.2	1.1	0.1
Kawau	1.00	22.3	2.8	12.8	1.6
Mercury	2.59	27.9	3.5	16.0	2.0
Total	3.59	50.2	6.4	28.9	3.7

3.2 2010 survey

3.2.1 Scallop population at the time of survey (June 2010)

Stratified random sampling by divers was conducted at 88 valid stations in June 2010, sweeping an estimated 10 077 m^2 of seabed (see Appendix 1); a total of 8749 scallops were collected and measured. Approximate length frequency distributions (scaled to estimated population size) varied considerably among strata (Figure 6), and when pooled by their respective locations (Figure 7). Figure 8 shows the length structure of the total population surveyed. Scallops of recreational legal size (100 mm or more shell length) were present in all strata sampled, but were in relatively high abundance only at Mercury Cove and, to a lesser extent, at Iris Shoal; all strata were dominated by scallops under legal size. Several cohorts were present at all strata, including a notable 30–60 mm (approximately) cohort, which is likely to be the result of successful larval settlement during the 2009–10 summer; the growth and survival of this cohort could lead to good recruitment to the fishable biomass over the next few years.

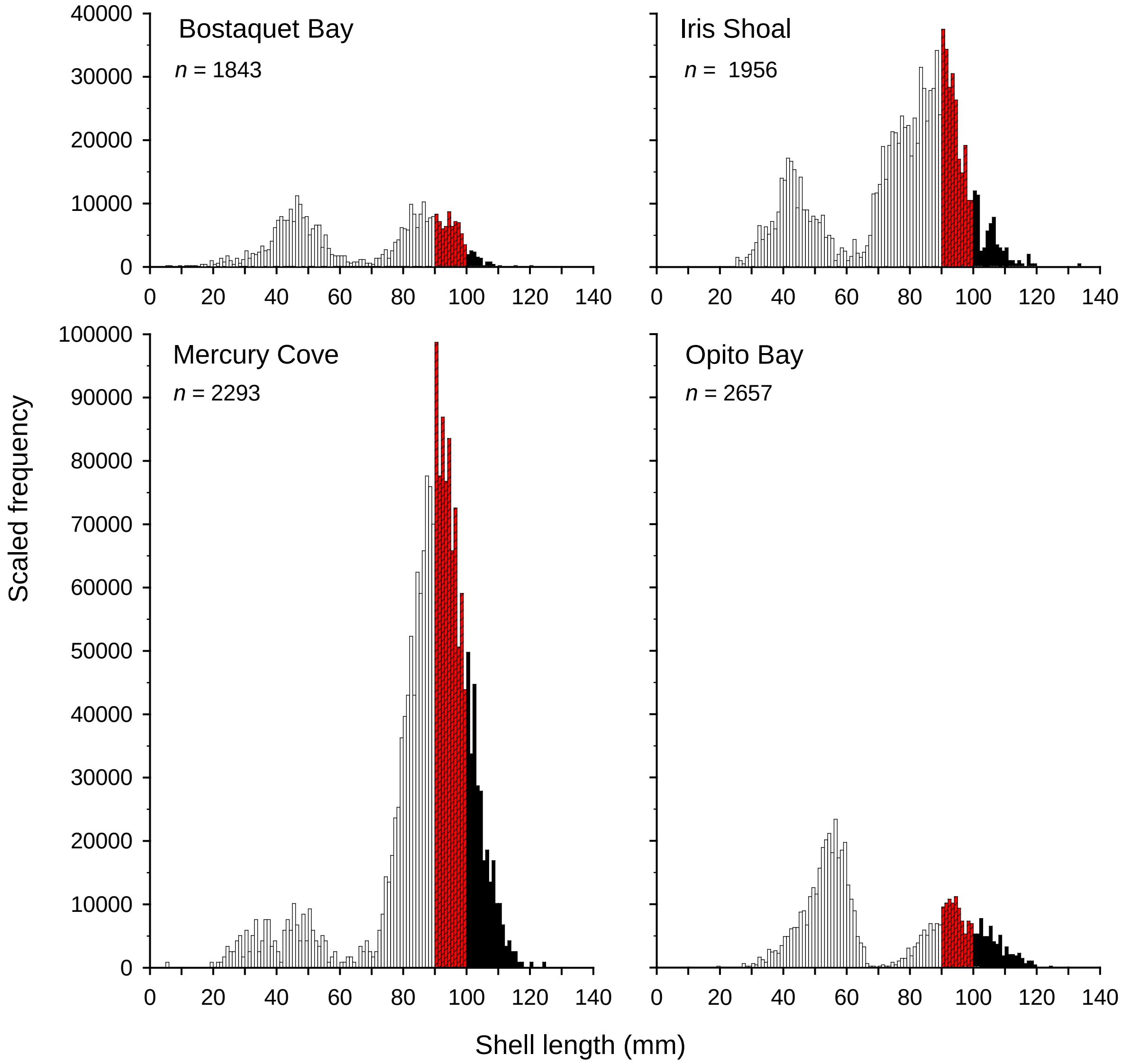

Figure 6: Length frequency distributions for the four strata surveyed during the 2010 surveys of scallops in Coromandel recreational fishing areas. Shaded bars show scallops 90 mm or more shell length and black bars show scallops 100 mm or more. n, number of scallops collected.

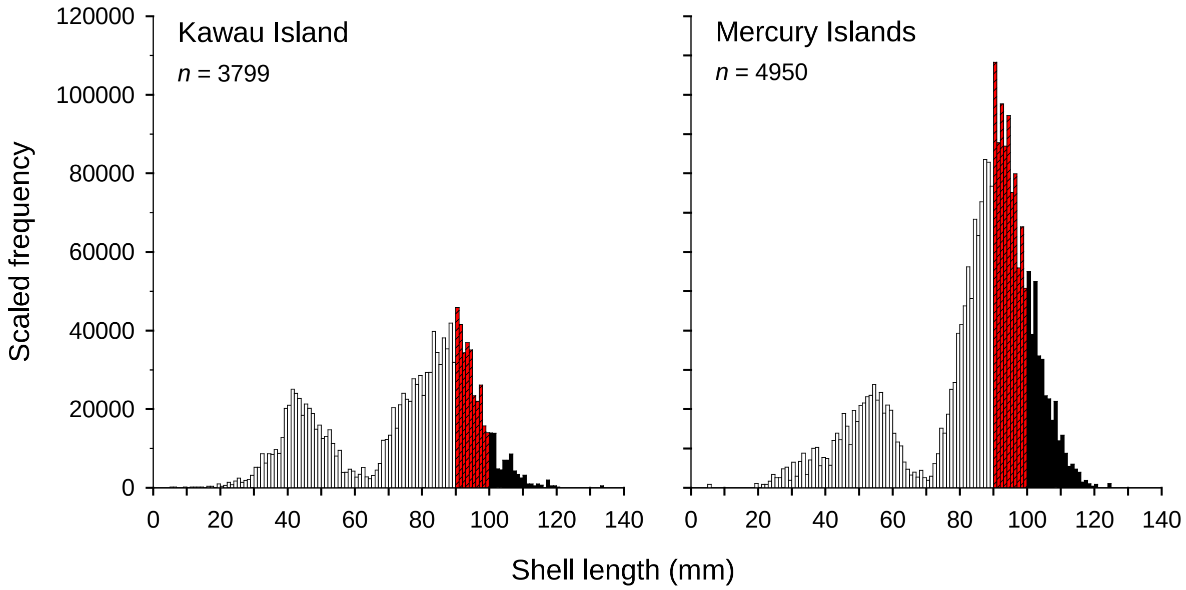

Figure 7: Length frequency distributions for the two locations surveyed during the 2010 surveys of scallops in Coromandel recreational fishing areas. Shaded bars show scallops 90 mm or more shell length and black bars show scallops 100 mm or more. n, number of scallops collected.

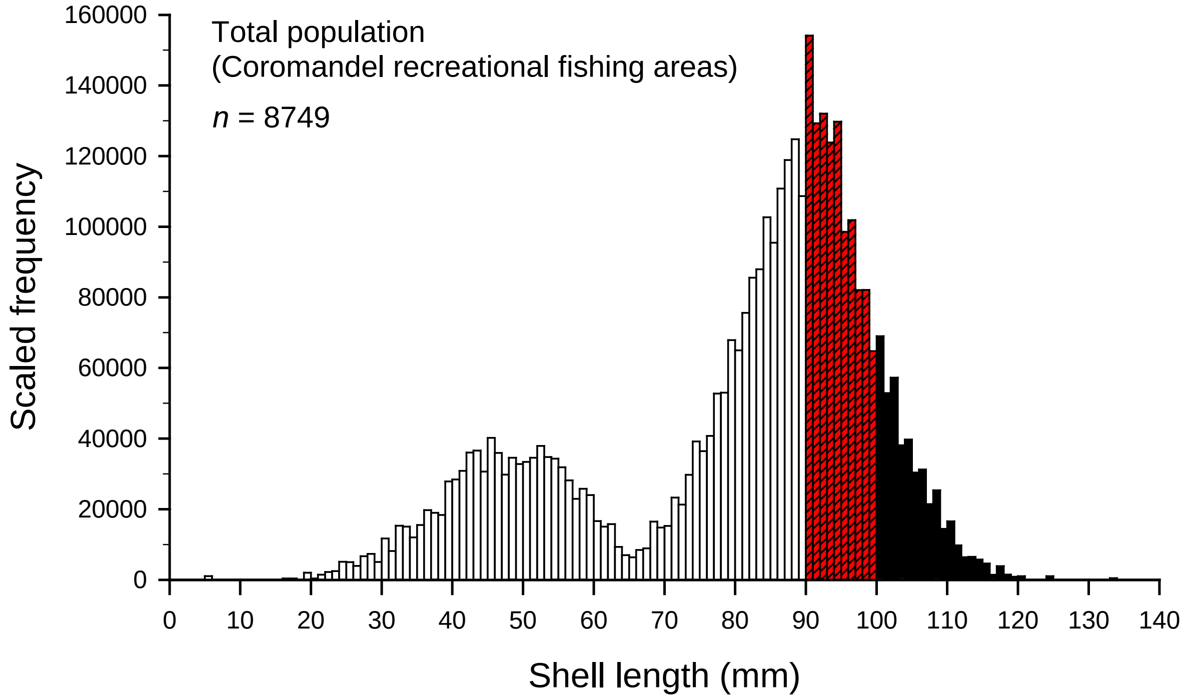

Figure 8: Length frequency distribution for the total area surveyed during the 2010 surveys of scallops in Coromandel recreational fishing areas. Shaded bars show scallops 90 mm or more shell length and black bars show scallops 100 mm or more. *n*, number of scallops collected.

At the level of individual stations (circular searches), the density of scallops of any size ranged from 0.01 to 5.36 m^{-2}, or zero to 0.65 m^{-2} for scallops of 100 mm or more shell length; these high densities were observed at Iris Shoal and Mercury Cove, respectively. At the stratum level, the density of scallops of legal size (100 mm or more shell length) was highest at Mercury Cove (0.19 m^{-2}), intermediate at Iris Shoal (0.10 m^{-2}), and low at Opito Bay (0.06 m^{-2}) and Bostaquet Bay (0.04 m^{-2})

(Table 6). At the location level, the density of legal scallops was highest at Mercury (0.14 m^{-2}) and lowest at Kawau (0.08 m^{-2}) (Table 6).

Using a simple parametric approach to estimation (and assuming 100% diver efficiency), the recruited biomass of scallops (100 mm or more shell length) at the time of the survey ranged from 1 to 29 t greenweight for the individual strata surveyed, with c.v.s ranging from 15 to 43% (Table 6). It should be noted that the strata were of quite different sizes (range 0.33–1.52 km^2, see Appendix 1) and, to a certain extent, biomass estimates were related to stratum area. Pooling the strata into their locations, biomass estimates were 8 and 36 t for Kawau and the Mercury Islands, respectively. The biomass estimate for the total area surveyed was 44 t greenweight. A resampling with replacement (bootstrapping) approach to estimation (resampling stations within strata and length-weight regressions) made very little difference to the estimates, or their uncertainty (Table 7). Estimated density and biomass of scallops 90 mm or more shell length (Table 8**)** and of scallops of any size (Table 9) are also presented below.

Table 6: Estimated density and biomass of scallops 100 mm or more shell length at the time of the 2010 surveys (using a simple parametric approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass (g m^{-2})	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	22	0.0370	0.0156	0.42	0.012	96.60	3.58	1.52	0.43	1.20
Iris Shoal	0.67	17	0.1029	0.0160	0.16	0.069	101.65	10.46	1.60	0.15	6.98
Mercury Cove	1.52	23	0.1926	0.0355	0.18	0.294	99.23	19.12	3.57	0.19	29.13
Opito Bay	1.06	26	0.0614	0.01	0.22	0.065	104.62	6.42	1.41	0.22	6.84
Kawau	1.00	39	0.0809	0.0119	0.15	0.081	100.88	8.16	1.18	0.14	8.18
Mercury	2.59	49	0.1387	0.0216	0.16	0.359	100.21	13.90	2.18	0.16	35.97
Total	3.59	88	0.1226	0.0159	0.13	0.440	100.34	12.30	1.60	0.13	44.15

Table 7: Estimated density and biomass of scallops 100 mm or more shell length at the time of the 2010 surveys (using a resampling with replacement approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass (g m^{-2})	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	22	0.0366	0.0153	0.42	0.012	97.25	3.56	1.50	0.42	1.19
Iris Shoal	0.67	17	0.1030	0.0152	0.15	0.069	102.33	10.54	1.52	0.14	7.04
Mercury Cove	1.52	23	0.1923	0.0348	0.18	0.293	99.76	19.18	3.54	0.18	29.23
Opito Bay	1.06	26	0.0609	0.0133	0.22	0.065	105.29	6.41	1.39	0.22	6.82
Kawau	1.00	39	0.0808	0.0116	0.14	0.081	101.43	8.19	1.16	0.14	8.21
Mercury	2.59	49	0.1384	0.0209	0.15	0.358	100.86	13.96	2.11	0.15	36.13
Coromandel	3.59	88	0.1223	0.0156	0.13	0.439	100.97	12.35	1.58	0.13	44.34

Table 8: Estimated density and biomass of scallops 90 mm or more shell length at the time of the 2010 surveys (using a simple parametric approach to estimation). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass (g m^{-2})	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	22	0.2338	0.0867	0.37	0.078	78.63	18.38	6.87	0.37	6.15
Iris Shoal	0.67	17	0.4459	0.0825	0.18	0.298	80.15	35.74	6.39	0.18	23.87
Mercury Cove	1.52	23	0.6621	0.1303	0.20	1.009	81.94	54.25	10.45	0.19	82.68
Opito Bay	1.06	26	0.1442	0.04	0.25	0.153	87.67	12.64	3.05	0.24	13.45
Kawau	1.00	39	0.3751	0.0621	0.17	0.376	79.83	29.95	4.84	0.16	30.02
Mercury	2.59	49	0.4492	0.0782	0.17	1.162	82.70	37.15	6.28	0.17	96.14
Total	3.59	88	0.4285	0.059	0.14	1.538	82.00	35.14	4.73	0.13	126.15

Table 9: Estimated density and biomass of scallops 1 mm or more shell length at the time of the 2010 surveys (using a simple parametric approach to estimation).

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass ($g\ m^{-2}$)	SEM	c.v.	Biomass (t green)
Bostaquet Bay	0.33	22	1.0666	0.1993	0.19	0.357	38.15	40.69	10.20	0.25	13.60
Iris Shoal	0.67	17	1.5439	0.3487	0.23	1.031	48.56	74.97	17.42	0.23	50.07
Mercury Cove	1.52	23	1.2694	0.2455	0.19	1.935	64.59	81.99	16.11	0.20	124.95
Opito Bay	1.06	26	0.5083	0.0991	0.20	0.541	40.88	20.78	4.43	0.21	22.11
Kawau	1.00	39	1.3847	0.2417	0.17	1.388	45.88	63.53	12.10	0.19	63.68
Mercury	2.59	49	0.9565	0.1502	0.16	2.475	59.41	56.83	9.66	0.17	147.06
Total	3.59	88	1.0760	0.1276	0.12	3.863	54.55	58.70	7.74	0.13	210.74

3.2.2 Projected scallop population at the start of the 2010 commercial season

Biomass at 15 July (the nominal start of the commercial fishing season) can be estimated (‘projected’) from the time of survey biomass by allowing for growth and assumed natural mortality (M = 0.5, spread evenly through the year) using a resampling with replacement (bootstrapping) approach to estimation (resampling stations within strata, length-weight regressions, and growth). The total biomass projected from the time of the survey (early June 2010) to the start of the commercial season (mid July 2010) was estimated to be 47.6 t greenweight for the recreational areas surveyed (Table 10). Projected biomass, therefore, was very similar to the time of survey biomass (e.g., Table 7). Estimating meatweight biomass at the start of the season is complicated by the unpredictability of the average meatweight recovery fraction (which depends on fisher behaviour as well as scallop biology). Using historical annual average meatweight recovery data (see Appendix 2) and a resampling with replacement approach to estimation resulted in an overall estimate of 6.1 t meatweight for the areas surveyed (Table 10).

Table 10: Projected density and biomass of scallops 100 mm or more shell length at 15 July 2010 (using a resampling with replacement approach to estimation, M = 0.5 spread evenly through the year, and average recovery of meatweight from greenweight). SEM, standard error of the mean.

Stratum/ Location	Area (km^2)	Stations	Mean density (m^{-2})	SEM	c.v.	Millions	Mean weight (g)	Mean biomass ($g\ m^{-2}$)	SEM	c.v.	Biomass (t green)	Biomass (t meat)	c.v.
Bost. Bay	0.33	22	0.0447	0.0180	0.40	0.015	94.72	4.23	1.73	0.41	1.41	0.18	0.44
Iris Shoal	0.67	17	0.1117	0.0160	0.14	0.075	100.44	11.22	1.58	0.14	7.49	0.95	0.21
M. Cove	1.52	23	0.2110	0.0373	0.18	0.322	98.24	20.73	3.71	0.18	31.59	4.02	0.23
Opito Bay	1.06	26	0.0644	0.0148	0.23	0.069	103.59	6.67	1.52	0.23	7.10	0.90	0.28
Kawau	1.00	39	0.0897	0.0126	0.14	0.090	99.43	8.92	1.23	0.14	8.94	1.13	0.20
Mercury	2.59	49	0.1500	0.0224	0.15	0.388	99.21	14.88	2.24	0.15	38.50	4.89	0.21
Total	3.59	88	0.1336	0.0167	0.12	0.480	99.24	13.26	1.66	0.13	47.59	6.05	0.16

3.2.3 2010 yield estimates

Current Annual Yield (CAY) estimates were provided for each of the surveyed areas on the basis of average start-of-season stock biomass projections. This ‘average’ outlook approach (assuming average growth, natural mortality of M = 0.5 spread evenly through the year, and historical average meatweight recovery) led to a start of season total recruited (100 mm in shell length or greater) biomass estimate of 48 t greenweight, or 6 t meatweight, for the recreational strata surveyed in 2010. The projected ‘average’ estimates of start of season biomass (Table 10) and the reference fishing mortality rate $F_{0.1}$ = 2.3616 yr^{-1} (previously reported as 0.984 for the 5 month duration of the commercial fishing season) were used to calculate CAY for the areas surveyed (Table 11). These estimates of CAY would have a c.v. at least as large as that of the estimates of start of season biomass, are sensitive to assumptions about recovery of meatweight from greenweight, and relate to the surveyed beds only.

Table 11: Estimates of Current Annual Yield (scallops 100 mm shell length or more) at 15 July 2010 at the Coromandel recreational fishing areas surveyed. CAY values were calculated using the Baranov catch equation and the reference fishing mortality rate $F_{0.1}$ (2.3616 yr^{-1}).

Stratum/Location	Area (km^2)	Biomass (t green)	Biomass (t meat)	CAY (t green)	CAY (t meat)
Bostaquet Bay	0.33	1.4	0.2	0.8	0.1
Iris Shoal	0.67	7.5	0.9	4.3	0.5
Mercury Cove	1.52	31.6	4.0	18.2	2.3
Opito Bay	1.06	7.1	0.9	4.1	0.5
Kawau	1.00	8.9	1.1	5.1	0.6
Mercury	2.59	38.5	4.9	22.1	2.8
Total	3.59	47.6	6.0	27.4	3.5

3.3 Investigation into bias in previous surveys

The method of divers deciding whether to conduct an 8-m or 5-m radius circular search at a given station introduces a bias, increasing the mean and decreasing the variance estimated. This bias is present to some degree in estimates for all recreational strata surveyed during the 2006–09 series except for Opito Bay, where 8-m searches were used routinely. This bias is not present for the 2010 estimates because all circular searches in 2010 were *a priori* 5-m radius, except in Opito Bay where all searches were 8-m radius.

The maximum potential extent of this bias was investigated by reanalysing the 2006–09 Coromandel survey data assuming that all searches with an 8-m radius contained zero scallops, rather than the actual number recorded. At the level of the total area surveyed, this resulted in estimates of mean density of scallops 100 mm or more that were about 10% lower (range = 6.6 to 16.9%), with c.v.s that were 3% higher (range = 2 to 4%), than those calculated from the original data (Figure 9; Table 12). At the level of individual strata or groups of strata, the magnitude of the bias was slightly larger (Table 12). The difference between the two sets of estimates represents the theoretical maximum possible bias introduced by the method. The actual bias, however, is likely to be much smaller because many of the 8-m circular searches contained numbers of scallops far greater than zero.

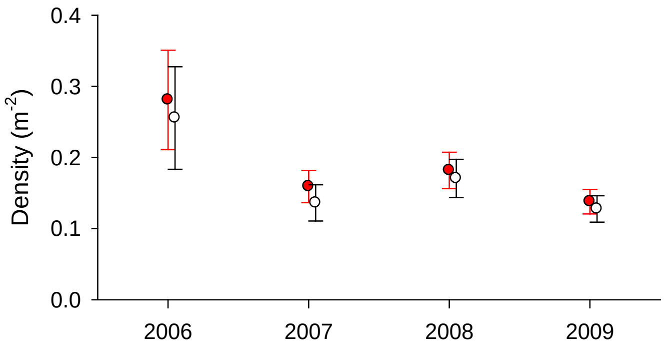

Figure 9: Mean density (m^{-2}, ± s.e.) of scallops 100 mm or more shell length for the 2006–09 diver surveys in Coromandel recreational fishing areas. Estimates calculated from the original survey data (closed symbols) are slightly positively biased, illustrated by the lower mean and slightly higher variance on the estimates produced from a reanalysis of the data assuming 8-m radius searches contained zero scallops (open symbols). Surveys were conducted in June–July. The latter set of estimates is offset for clarity. Note that the revised 2009 strata were used to calculate scallop density in each survey year.

Table 12: Estimated mean density and c.v. for scallops 100 mm shell length or more at the time of the 2006–09 diver surveys (June–July) using the original data and by assuming 8-m radius searches chosen by divers would have contained zero scallops if only a 5-m search had been conducted. Comparison of the two sets of estimates permits the calculation of maximum potential bias (proportional difference) introduced. Note that the revised 2009 strata were used to calculate scallop density in each survey year.

		Using original data		Assuming 8-m radius searches were zero		Maximum potential bias introduced	
Year	Stratum/Grouping	Density (m^{-2})	c.v.	Density (m^{-2})	c.v.	On density	On c.v.
2006	Bostaquet Bay	0.3396	0.2882	0.2956	0.3549	0.15	-0.07
	Iris Shoal	0.3007	0.1673	0.2728	0.2094	0.10	-0.04
	Mercury Cove	0.4335	0.3729	0.3955	0.4208	0.10	-0.05
	Opito Bay	0.0315	0.3345	0.0315	0.3345	0.00	0.00
	Kawau	0.3137	0.1492	0.2804	0.1844	0.12	-0.04
	Mercury	0.2682	0.3553	0.2458	0.3990	0.09	-0.04
	Total	0.2809	0.2489	0.2555	0.2825	0.10	-0.03
2007	Bostaquet Bay	0.1247	0.2020	0.1247	0.2020	0.00	0.00
	Iris Shoal	0.0876	0.2179	0.0803	0.2597	0.09	-0.04
	Mercury Cove	0.3090	0.1701	0.2580	0.2288	0.20	-0.06
	Opito Bay	0.0000	0.0000	0.0000	0.0000	0.00	0.00
	Kawau	0.1000	0.1525	0.0951	0.1708	0.05	-0.02
	Mercury	0.1820	0.1701	0.1519	0.2288	0.20	-0.06
	Total	0.1591	0.1428	0.1361	0.1871	0.17	-0.04
2008	Bostaquet Bay	0.1004	0.2588	0.0996	0.2622	0.01	0.00
	Iris Shoal	0.4325	0.1526	0.3939	0.1891	0.10	-0.04
	Mercury Cove	0.2055	0.2555	0.1961	0.2748	0.05	-0.02
	Opito Bay	0.0156	0.3959	0.0156	0.3959	0.00	0.00
	Kawau	0.3217	0.1393	0.2958	0.1704	0.09	-0.03
	Mercury	0.1275	0.2434	0.1219	0.2611	0.05	-0.02
	Total	0.1817	0.1410	0.1704	0.1579	0.07	-0.02
2009	Bostaquet Bay	0.0493	0.3207	0.0464	0.3460	0.06	-0.03
	Iris Shoal	0.3010	0.2190	0.2654	0.2723	0.13	-0.05
	Mercury Cove	0.1692	0.1662	0.1613	0.1841	0.05	-0.02
	Opito Bay	0.0181	0.3031	0.0181	0.3031	0.00	0.00
	Kawau	0.2170	0.2038	0.1924	0.2519	0.13	-0.05
	Mercury	0.1070	0.1561	0.1024	0.1721	0.05	-0.02
	Total	0.1377	0.1252	0.1275	0.1455	0.08	-0.02

3.4 Length frequency distributions of scallops in non-commercial areas, 2006–10

The 2006–10 time series of length frequency distributions (scaled to estimated population size) from the diver surveys of scallops in recreational areas are shown by stratum in Figure 10 and grouped by location in Figure 11. The length structure of the population at Mercury Cove appears to have been relatively stable, with good proportions of juvenile and adult (more than 70 mm) scallops present in all years (Figure 10). Modal progression during the time series can be seen in the other strata, which is likely to represent sporadic pulses of good settlement and growth, sometimes resulting in significant recruitment to the harvestable size (non-commercial MLS of 100 mm). For example, a cohort of juvenile scallops at Iris Shoal with a modal size of about 30 mm was present in 2006, which appears to have grown into a modal size of about 90 mm in 2007, and 100 mm by 2008, resulting in a significant increase in the recruited (harvestable) density of scallops between 2007 and 2008 (Figure 10).

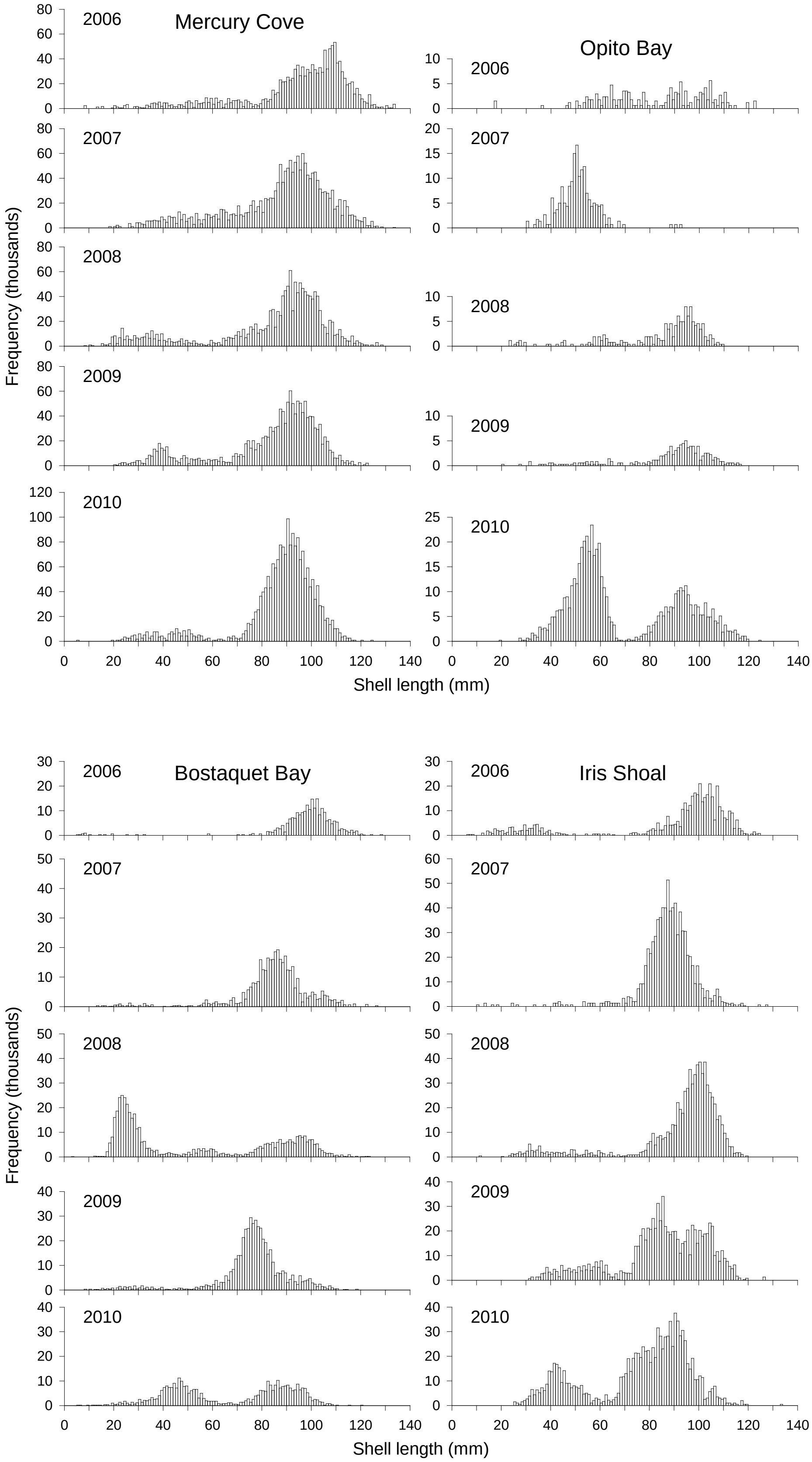

Figure 10: Length frequency distributions for the four strata (Mercury Cove and Opito Bay at the Mercury location; Bostaquet Bay and Iris Shoal at the Kawau location) surveyed during the 2006–10 surveys of scallops in Coromandel recreational fishing areas.

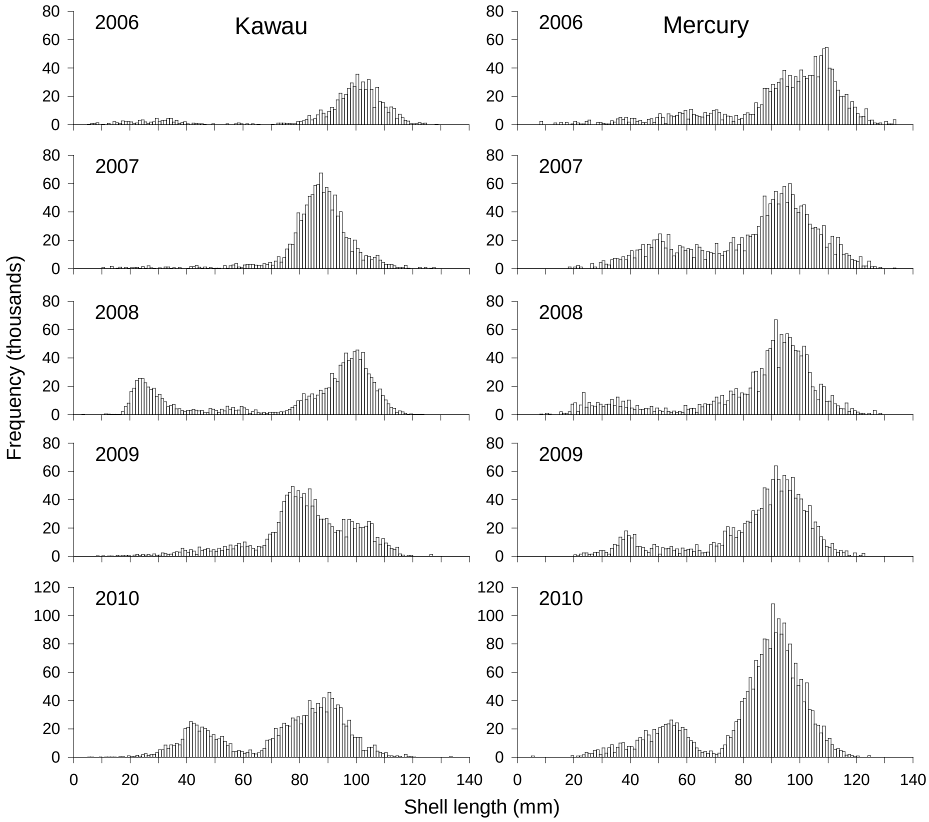

Figure 11: Length frequency distributions for the two locations surveyed during the 2006–10 surveys of scallops in Coromandel recreational fishing areas.

3.5 Comparison of densities in commercial and non-commercial areas, 2006–10

The 2006–10 time series of data from the diver surveys of scallops in recreational fishing areas (Williams et al. 2008, Williams 2009b, c, present study) and dredge surveys in commercial scallop fishing areas (Williams et al. 2007, Williams 2008, 2009a, Williams & Parkinson 2010, Williams et al. 2010) can be examined to compare trends in scallop abundance in areas open and closed to commercial dredging.

From both the recreational and commercial surveys, scallop densities have been estimated for the start of the season at the relevant stratum, region, and fishery area level for two length bins of interest: scallops 100 mm or more, and scallops 90 mm or more. The same resampling with replacement (bootstrapping) approach to estimation was used as described earlier. For the commercial surveys, corrections for dredge efficiency were applied using preliminary estimates from a new parametric model of dredge efficiency under development through Ministry of Fisheries projects SCA200802 and SAP200913 (see Appendix 3).

First, comparisons of scallop density over the 5-year time series were made at a fine spatial scale, between recreational and commercial strata located immediately adjacent to each other at two small bays within the same region (Mercury) of the Coromandel fishery: Mercury Cove and Opito Bay. The trend in density was roughly similar for the recreational and commercial strata at both bays (Figure 12). This may be expected because of the close proximity between the recreational and commercial strata; the latter essentially occupy the deeper portion of each bay. This similarity was not observed between the recreational strata and all commercial strata in the Mercury region, however, suggesting spatial variability in the putative relationship in abundance among beds within the region.

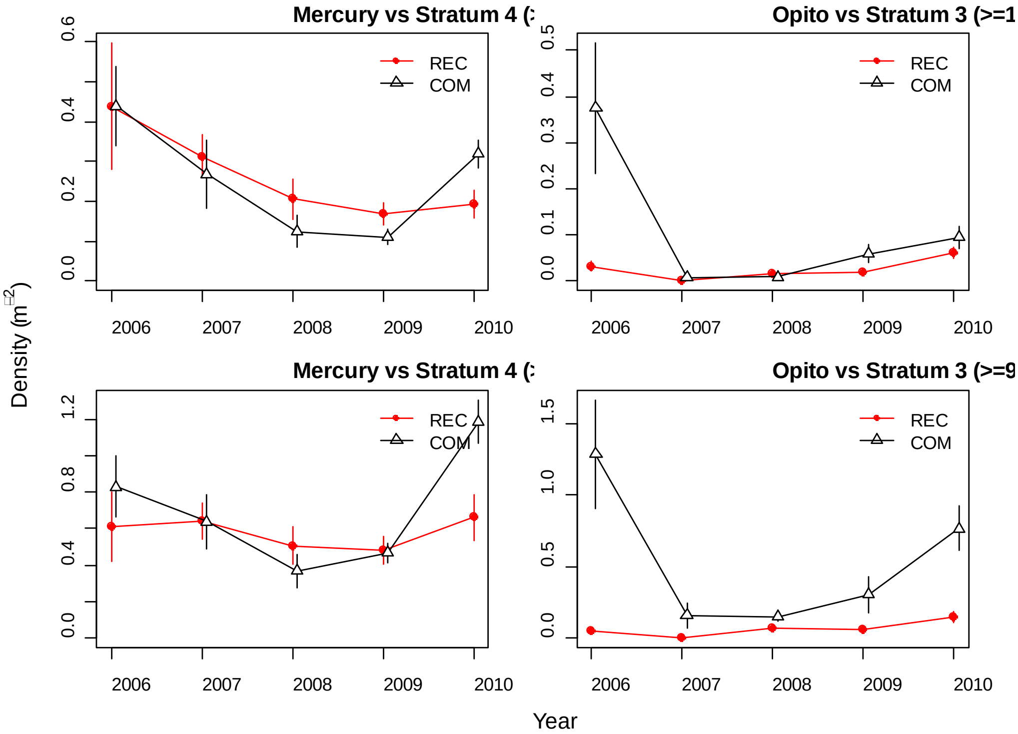

Figure 12: Mean density (m^{-2}, ± s.e.) of scallops at recreational (closed circles, red lines) and commercial (open triangles, black lines) strata at Mercury Cove (left) and Opito Bay (right) in the Coromandel scallop fishery, 2006–10. 'Mercury' refers to the recreational stratum and 'Stratum 4' refers to the commercial stratum at Mercury Cove. Similarly, 'Opito' refers to the recreational stratum and 'Stratum 3' refers to the commercial stratum at Opito Bay. Densities are shown for scallops 100 mm or more shell length (top two plots) and 90 mm or more (bottom two plots).

Second, trends in density between the recreational and commercial areas became less similar when examined at a larger scale, among the different geographic regions of the Coromandel fishery. For scallops 100 mm or more, the trend in the Mercury recreational areas was apparently fairly similar to that in the commercial areas of the Mercury and Colville regions, and perhaps to a lesser extent the Bay of Plenty region. At Little Barrier, however, the trend was different between 2008 and 2009, when density increased substantially in the commercial beds; for scallops 90 mm or more, these apparent trends became even less clear (Figure 13). There were no consistent trends in density between the Kawau recreational areas and the commercially fished regions (Figure 14).

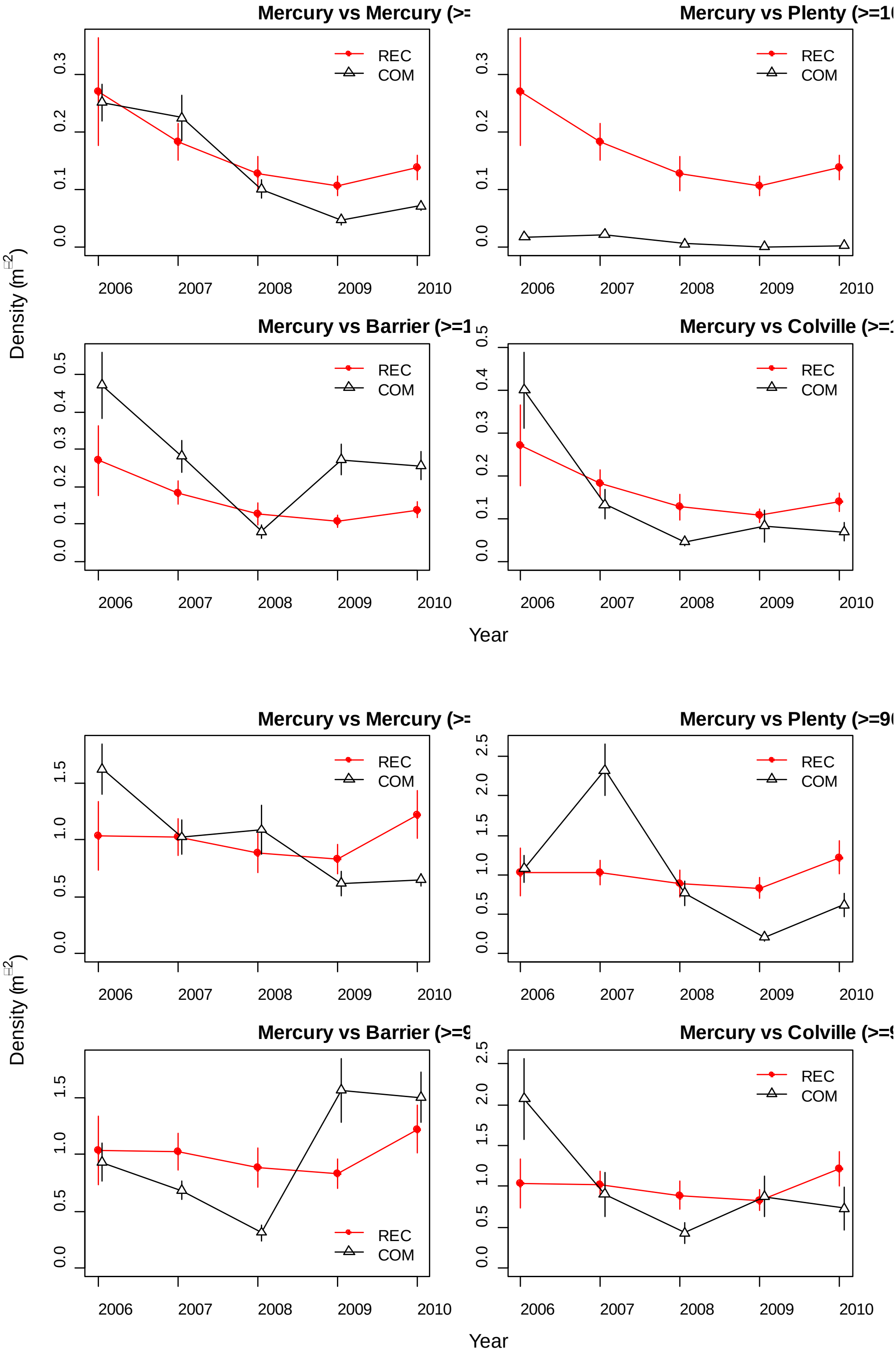

Figure 13: Mean density (m^{-2}, ± s.e.) of scallops in recreational fishing areas at Mercury (closed circles, red lines; Mercury Cove and Opito Bay strata combined) and commercial fishing areas (open triangles, black lines) in four regions of the Coromandel scallop fishery (Mercury, Barrier, Colville, Bay of Plenty), 2006–10. Densities are shown for scallops 100 mm or more shell length (top four plots) and 90 mm or more (bottom four plots).

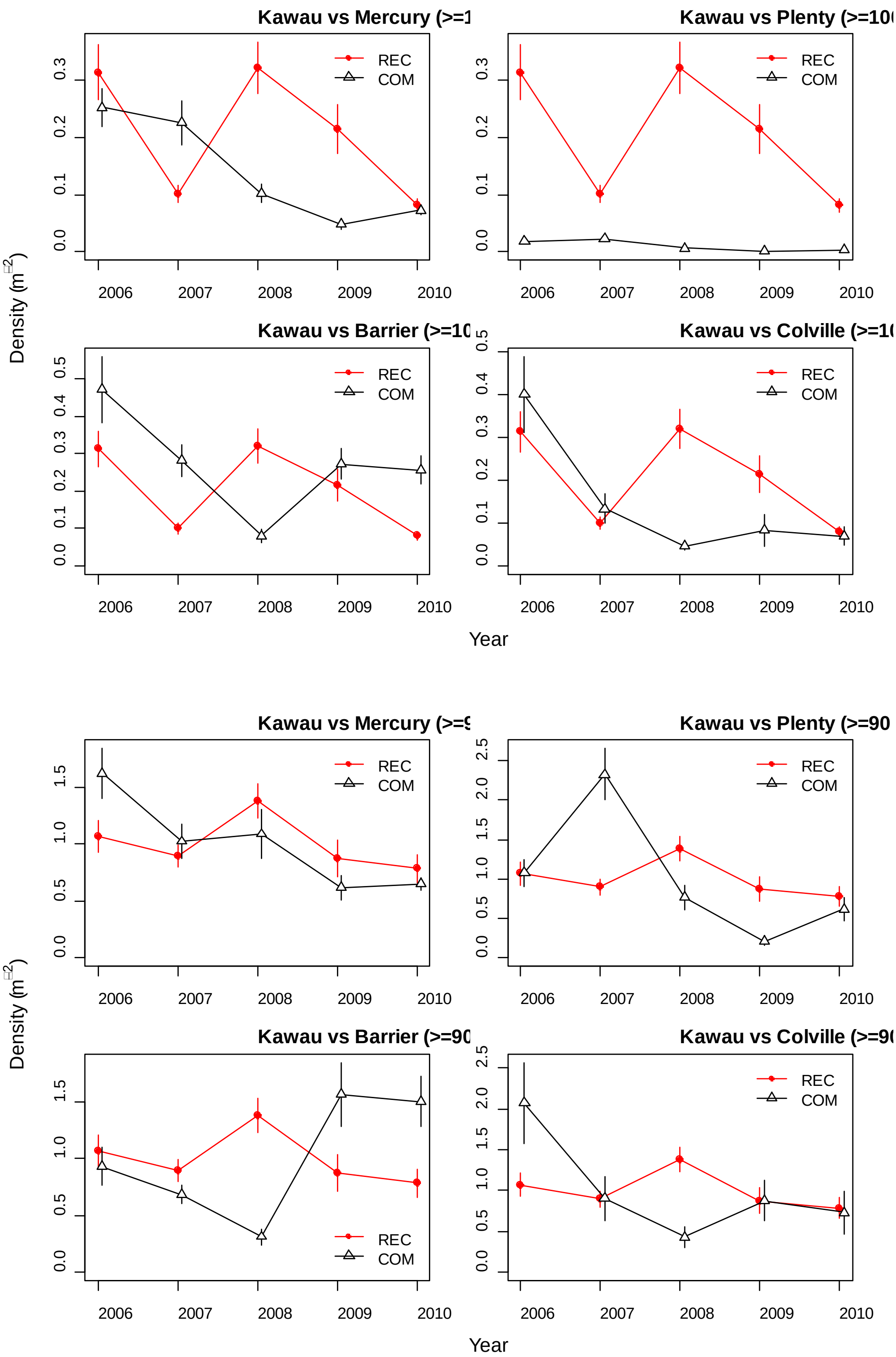

Figure 14: Mean density (m^{-2}, ± s.e.) of scallops in recreational fishing areas at Kawau (closed circles, red lines; Iris Shoal and Bostaquet Bay strata combined) and commercial fishing areas (open triangles, black lines) in four regions of the Coromandel scallop fishery (Mercury, Barrier, Colville, Bay of Plenty), 2006–10. Densities are shown for scallops 100 mm or more shell length (top four plots) and 90 mm or more (bottom four plots).

Third, trends in density between the recreational and commercial areas were examined at the overall level of both the Coromandel and Northland fisheries. Overall, the density of scallops 100 mm or more shell length was highest in 2006 and subsequently declined, in both fisheries (Figure 15). This decrease from 2006 to 2010 was consistent across almost all strata, regardless of their status as either commercial or recreational fishing areas; exceptions were for the Iris Shoal and Opito Bay recreational strata, which both showed an increase in density between 2007 and 2008 (which appears to have continued to 2010 at Opito Bay), and in the commercial strata at Little Barrier Island and Colville, which both showed a marked increase in density between 2008 and 2009. However, whilst a similar overall declining trend in density is evident in the commercial areas for scallops 90 mm or more shell length, there is no such trend in the recreational areas, where density has remained relatively stable (Figure 15).

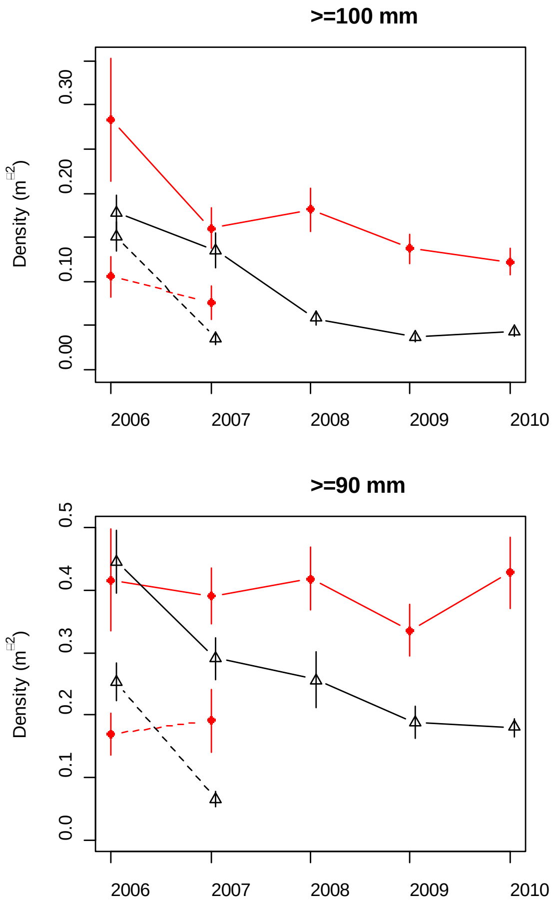

Figure 15: Mean density (m^{-2}, ± s.e.) of scallops 100 mm or more shell length (top) and 90 mm or more (bottom) in recreational (closed circles, red lines) and commercial (open triangles, black lines) areas surveyed in the Coromandel (solid lines) and Northland (dashed lines) scallop fisheries, 2006–10.

Correlations between the densities of scallops in the different recreational and commercial strata from the 2006–10 survey data were also investigated at the relevant stratum and statistical area level for different scallop size ranges (30–59, 60–89, 90–99 and more than 100 mm), but it is unclear how strong a correlation should be expected between the density in the different areas, and in which size categories. Given that only five years of survey data are available, correlation analysis was considered uninformative and unwarranted.

4. DISCUSSION

4.1 Relationship in abundance between recreational and commercial areas

The overall objective of this research programme was to investigate the relationship in scallop abundance between the main commercial and recreational scallop beds. The diver surveys of scallops in recreational fishing areas conducted in 2006 (Williams et al. 2008), 2007 (Williams 2009b), 2008 (Williams 2009c), 2009, and 2010 (present study) have been the first surveys of these non-commercial scallop beds for a number of years, and, ideally, data collected over a longer series of years would be required before this relationship could be fully examined.

Historical data from previous (1990s) scallop surveys in the Northland and Coromandel fisheries were used by Williams (2009b) to conduct a retrospective analysis of the relationship in scallop abundance between areas open and closed to commercial fishing. Before about 1997, some of the shallower, inshore scallop beds formed part of the commercial scallop fishery areas, and, therefore, were surveyed as part of earlier commercial scallop biomass surveys. During the mid to late 1990s, commercial fishers voluntarily agreed not to fish in some of these areas, which were are of high interest to recreational fishers (Cryer & Parkinson 1999). Subsequently, certain voluntary closed areas (VCAs) became legally closed to commercial scallop fishing in an attempt to separate, as far as possible, the commercial and non-commercial fisheries. Discerning trends in the historical abundance of scallops in these areas was difficult because of the limited data available, but, for the Mercury Islands region of the Coromandel fishery, scallop density appeared to be reasonably well linked between the areas formerly open and now closed to commercial dredging (Williams 2009b).

The present study also found trends in scallop density were fairly similar at a fine spatial scale, between adjacent recreational and commercial strata in two bays at the Mercury region of the Coromandel fishery. The existence of such a link may not be surprising because the open and closed areas form part of the same embayment at each site, so each area could be expected to receive a similar supply of scallop larvae and have similar environmental conditions which affect scallop growth and mortality. At broader spatial scales, among different regions of the fisheries, apparent trends in density between recreational and commercial areas became weaker.

There are several factors which complicate comparisons between the recreational and commercial areas surveyed. Different survey methods were used in the recreational (diver) and commercial (dredge) areas; dredge tows sample a much larger area of seabed than circular searches by divers, and, because of the patchiness inherent in the spatial distribution of scallops, this probably reduces the observed variability in scallop density among stations. There is also uncertainty inherent in correcting for dredge efficiency. Ideally, the same survey methodology should be applied to both commercial and non-commercial areas to allow fair comparisons between the two. Although sampling recreational fishing areas with a commercial dredge may be inappropriate, diver surveys of the commercial areas of interest could be feasible. The commercial strata surveyed were also much larger (2.7–62.9 km^2) and deeper (mean depth 22 m) than the recreational strata surveyed (0.3–2.1 km^2, mean depth 11 m), and modifications to the commercial strata surveyed over time further complicate comparisons.

The recreational size limit (100 mm) means that there should be minimal fishing mortality on scallops below this size (there may be a low level of incidental mortality from recreational dredges). In the commercially dredged areas, however, the incidental effects of dredging are such that all scallop sizes will incur some fishing related mortality. If fishing occurs within the commercial strata, then the direct removals of harvestable scallops and the incidental effects of dredging would be expected to reduce the strength of any relationship in abundance between the recreational and commercial areas.

Overall, the 2006–10 survey data tentatively suggest a link between adjacent strata within a region, whilst scallop populations at more distant strata or regions appear to be less well associated. We must be cautious in interpreting any putative links in abundance between the commercial and recreational scallop beds, however, because five years of survey data (N.B. only two years for the Northland fishery) are probably insufficient to conclude a trend, and correlation analysis was considered uninformative and unwarranted. With a relatively long (15 year) time series of commercial dredge surveys available, there could be potential merit in analysing correlations in abundance between commercial scallop strata in relation to their degree of geographic separation, but that would probably require the development of a stock assessment model for scallops to account for the effects of fishing (e.g., removals as catch, incidental mortality on scallops and habitats) and environment forcing on the dynamics of the scallop population.

A management strategy evaluation of the Coromandel fishery (Haist & Middleton 2010) modelled the SCA CS stock as four essentially independent sub-stocks (Hauraki Gulf, Mercury Islands, Bay of Plenty, and Barrier/Colville) ; this approach assumes recruitment to each substock is reliant on larvae produced by local spawning densities, with no dispersal of larvae between substocks. This may be a conservative assumption given the three week duration of the larval dispersal phase, but correlation and auto-correlation in catch and survey biomass were reported among the substocks, with the Hauraki Gulf and Mercury substocks showing the strongest autocorrelations. This was thought likely to reflect auto-correlation in recruitment within areas and correlation of recruitment among areas (Haist & Middleton 2010). A different investigation into the utility of projecting scallop surveys forward to predicting future year's stock biomass also showed evidence of spatial and temporal autocorrelation within the Coromandel fishery (Tuck 2011), suggesting that environmental factors affecting scallop growth and recruitment may be operating at regional and fishery-wide scales.

If the dynamics of scallop populations do indeed vary among the different regions of the fisheries, then stock assessment and management of scallops at finer spatial scales than used currently would be sensible; the single stock-wide approach used currently is probably inappropriate. Understanding population connectivity of scallops will require future work on investigating the biological and hydrodynamic processes involved in the transport of larvae and deriving larval origins and dispersal pathways using geochemical, genetic, or artificial markers (Cowen et al. 2007).

4.2 CAY estimates

Estimates of CAY were based on biomass estimates from the survey and a reference *F* calculated on the basis of the commercial fishery. Although the latter is not ideal, the potential error introduced is considered to be small (M. Cryer, Ministry for Primary Industries, Wellington, pers comm.). Future studies could investigate specific reference fishing mortality rates for recreational fisheries.

The recreational fishery is currently managed on the basis of a daily bag limit (20 scallops per person, and divers may also take additional scallops for up to a maximum of two safety people per vessel), a minimum legal size (100 mm), and a restricted fishing season (1 September to 31 March as of 2007, previously 15 July to 14 February). However, the distribution and overall level of landings (current and historic) from the recreational scallop fishery are uncertain, although Holdsworth & Walshe (2009) provide a recent estimate for part of the Coromandel area, and there is no limit on the overall level of recreational fishing effort or harvest.

The CAY estimates presented here are specific to the four recreational strata surveyed, which, in total, represent a small (3.6 km^2) but unknown proportion of the Coromandel recreational scallop fishing area. Presently, there is no information on how current non-commercial scallop landings from these specific areas relate to these yield estimates, and, therefore, to what extent the scallop populations in these areas are being exploited. Within the existing management system, management of the non-commercial scallop fishery to a CAY (or other landings limit) would require a good understanding of the relationship between effort, the bag limit, and total landings, which is currently not available.

5. CONCLUSIONS

1. Diver surveys of two Coromandel recreational scallop fishing locations (four recreational strata) were conducted in July 2009 and June 2010, the latter marking the fifth and final survey of these Coromandel recreational scallop beds in this 2006–10 survey series.

2. Absolute biomass of scallops 100 mm or more shell length (the recreational minimum legal size) at 15 July (the nominal start of season for the Coromandel commercial scallop fishery) for the areas surveyed was predicted to be about 50.2 t greenweight or 6.4 t meatweight in 2009 (with c.v.s of about 13%), and 47.6 t greenweight or 6.1 t meatweight in 2010 (with c.v.s of about 13% and 16%, respectively).

3. Yield estimates (CAY based on $F_{0.1}$) were calculated using estimates of projected biomass and the reference fishing mortality rate $F_{0.1}$ (2.3616), which suggested a total meatweight yield of 3.7 t in 2009 and 3.5 t in 2010 for the recreational areas surveyed.

4. It is unclear how current recreational landings relate to the CAY estimates for the areas surveyed, or how a CAY can be incorporated into the current recreational scallop fishery management system.

5. Scallop densities in areas open and closed to commercial dredging were compared using data from the 2006–10 diver and dredge surveys.

6. Scallop abundance in commercial and some recreational areas seem to have varied in similar ways but it is difficult to draw firm conclusions about the nature of this relationship.

6. ACKNOWLEDGMENTS

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APPENDICES

Appendix 1: Stratum details and catch of scallops

Appendix 1.1: Stratum definitions and station allocations for the diver surveys of recreational scallop areas in the Coromandel fishery, July 2009 (top table) and June 2010 (bottom table). Locations and strata were originally developed and surveyed for the first time in 2006 (Williams et al. 2008) after consultation with the Ministry of Fisheries, and commercial and recreational scallop fishers. The same strata were surveyed again in 2007 (Williams 2009b) and 2008 (Williams 2009c). The strata in 2009 were modified slightly from those used in the 2006–08 surveys by redrawing the stratum boundaries to better reflect the extent of the scallop bed (target population) at each site. The revised stratum boundaries excluded areas of the seabed that the 2006–08 surveys had shown were unsuitable habitats for scallops (i.e., too shallow, patch reef).

Year	Location	Stratum	Area (km^2)	Stations	Stations km^{-2}	Swept area (m^2)	Depth (m)			Scallops
							mean	min	max	
2009	Kawau	Bostaquet Bay	0.33	19	56.83	2 077	13.6	8.3	18.2	1 981
		Iris Shoal	0.67	13	19.46	1 389	10.7	7.9	12.6	1 481
	Mercury	Mercury Cove	1.52	24	15.75	2 498	16.6	5.2	25.4	1 911
		Opito Bay	1.06	19	17.86	3 820	14.1	8.5	17	340
	Total	All 4 strata	3.59	75	20.89	9 783	14.2	5.2	25.4	5 713
2010	Kawau	Bostaquet Bay	0.33	22	65.80	1 728	14.1	9	18.2	1 843
		Iris Shoal	0.67	17	25.45	1 316	10.3	8.2	12	1 956
	Mercury	Mercury Cove	1.52	23	15.09	1 806	16.8	7.3	25.7	2 293
		Opito Bay	1.06	26	24.44	5 228	13.8	9.3	17.8	2 657
	Total	All 4 strata	3.59	88	24.51	10 077	14.0	7.3	25.7	8 749

Appendix 2: Meatweight recovery for the Coromandel commercial fishery, 1995–2009

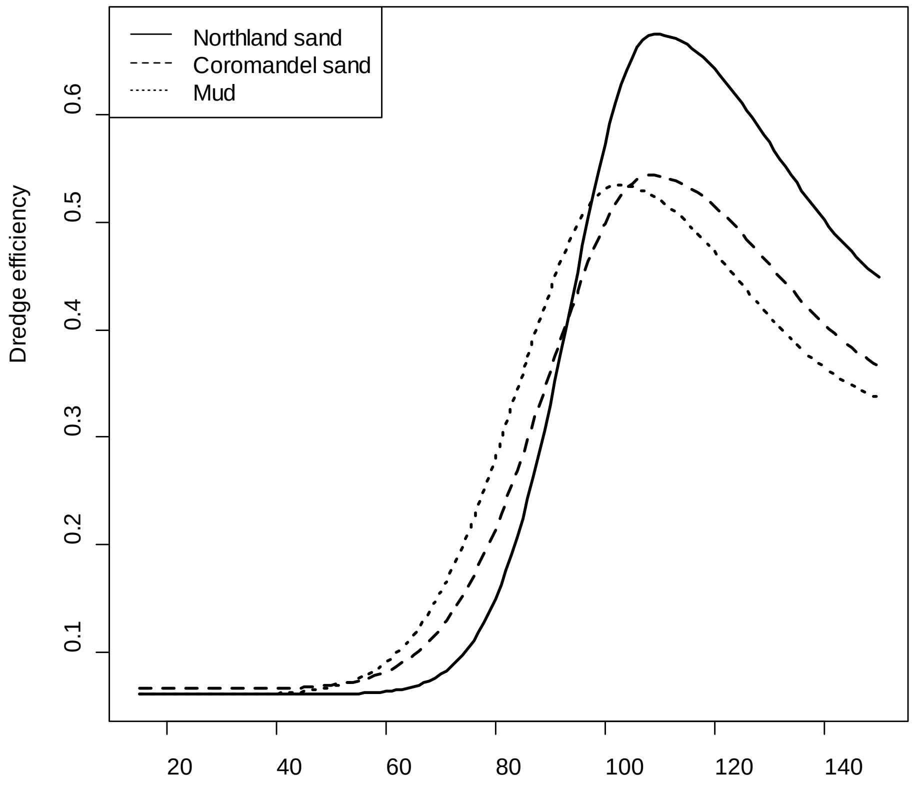
Appendix 2.1: Estimated average recovery (%) of meatweight from greenweight for Coromandel commercial scallop seasons 1995–2009. Values for 1995–2002 were estimated by Cryer & Parkinson (2006), based on the ratio of actual measured meatweight (reported on the bottom half of CELRs) to estimated greenweight (often reported on the top half of CELRs), screened to remove extreme outliers (recovery less than 5% or more than 30%). Values for 2004–2009 were estimated ((Williams & Parkinson 2010), based on the ratio of measured meatweight to measured greenweight, using data supplied by the Coromandel fishery's principal processor of scallops (Whangamata Seafoods Ltd.). –, no estimate.

Year	Recovery (%)
1995	13.7
1996	13.7
1997	12.9
1998	–
1999	10.4
2000	9.9
2001	12.5
2002	15.6
2003	–
2004	12.4
2005	12.4
2006	12.1
2007	10.3
2008	11.4
2009	11.6

Appendix 3: Dredge efficiency estimates

Dredges are not 100% effective at retaining scallops and efficiency can vary widely (e.g. Cryer & Morrison 1997b, Cryer & Parkinson 1999). Consequently, estimates of scallop abundance and biomass derived from dredge survey data are sensitive to assumptions about dredge efficiency, and a critical input into the stock assessment model is the calculated dredge efficiency. Dredge efficiency varies with scallop size. Few of the smallest scallops are retained by the dredge, and efficiency typically increases with size to reach a maximum at some scallop size. Above this size there may be a decline in efficiency. Efficiency may also vary with substrate type.

Ministry of Fisheries projects SCA200802 and SAP200913 recently reviewed dredge efficiency studies in the Coromandel and Northland scallop fisheries, and modelled the data available using a Bayesian approach to examine the factors affecting dredge efficiency, and provide best estimates for use in dredge survey analysis. In the present study, preliminary estimates of efficiency (curves shown in Appendix 3.1 below) available in April 2011 from the new model under development were applied to the commercial survey data to ‘correct’ for dredge efficiency, using different efficiency curves for stations in sandy and muddy areas of the Coromandel area surveyed. Note that subsequent to that analysis, the new efficiency model was further refined and the final model was reported by Bian et al (2012). The small difference between the preliminary efficiency estimates and the final estimates should not affect the comparison of trends in scallop abundance in areas open and closed to commercial dredging reported in the present study (section 3.5).



Appendix 3.1: Dredge efficiency estimates derived from preliminary modelling of dredge efficiency studies (projects SCA200802 & SAP200913). Note that these estimates were the best available at the time the analysis was conducted in the present study; they are slightly different from those produced from final modelling work reported by Bian et al. (2012).