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Management Strategy Evaluation for the Coromandel Scallop Fishery

New Zealand Fisheries Assessment Report 2014/48

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EXECUTIVE SUMMARY

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This report summarizes a management strategy evaluation (MSE) for the Coromandel scallop resource (SCA CS) that was conducted at the request of the commercial fishing industry (Coromandel Scallop Fishermen's Association). The MSE investigates two approaches for setting total allowable commercial catches (TACCs) and managing the commercial fishery. The first approach, based on the current management system, sets a low base TACC which can be increased in-season based on the results of a resource survey (*Survey* rule). The second approach sets higher TACCs and closes individual scallop beds when catch rates (CPUE) fall below a specified threshold level (*LimitCPUE* rules).

The key steps of the MSE were: discussion with industry members to ascertain their objectives for the fishery; development of an operating model to reflect stock and fishery dynamics; analysis of historical scallop survey and fishery CPUE data to provide a basis for tuning the operating model; and simulations of alternative scenarios for managing the fishery.

Evaluating the alternative decision rules investigated in this MSE requires consideration of the conflicting objectives of maximizing catch (or economic value), minimizing inter-annual variability in the catch, and ensuring safety (conservation) of the resource. The Harvest Strategy Standard (HSS) provides the necessary guidance for ensuring safety of the resource and compliance with the Fisheries Act. The HSS defines target and limit reference points for fisheries resources which are consistent with the requirement of the Fisheries Act to maintain stocks at or above, or move stocks to, a level that can produce maximum sustainable yield.

An appropriate target reference point for the Coromandel scallop resource is B_{msy} as it is clearly defined within the operating model. Under constant fishing mortality rate simulations, B_{msy} was estimated to be 33% of B_0. All decision rules examined under the *baseline* simulations attain the HSS requirement of a 50% probability or higher of maintaining the stock above B_{msy}. Additionally, all *LimitCPUE* decision rules and many of the *Survey* rules meet the requirement of a 2% probability or lower of stock biomass falling below 10%B_0 for the *baseline* trials.

Of the three HSS criteria, the 10% probability of stock biomass being below 20% B_0 is the most stringent. For the *baseline* simulations, all *LimitCPUE* rules with a CPUE threshold above 40 kg/hr meet the 20%B_0 criterion but only the *Survey* rule with a low survey biomass multiplier and low base TACC meets this criterion.

The two types of decision rules examined, the *LimitCPUE* and the *Survey*-based rules, behave quite differently with the *LimitCPUE* rules approximating constant catch rules and the *Survey* rules approximating constant harvest rate rules. As such the *Survey* rules have higher catch variability at the same mean catch level of *LimitCPUE* rules. However the rule types are not strict constant catch and constant harvest rate rules, and as such their behaviour differs somewhat from those forms of harvest strategy. Results from this MSE suggest that similar mean catches can be attained at similar risk levels for the *LimitCPUE* and *Survey* rules. The *LimitCPUE* rules are not strictly constant catch rules as scallop beds are closed when catch rates fall below defined thresholds, thus they function somewhere between constant catch and constant escapement type rules.

1. INTRODUCTION

At the request of the commercial fishing industry (Coromandel Scallop Fishermen's Association), SeaFIC conducted a management strategy evaluation (MSE) for the Coromandel scallop resource (SCA CS). The MSE investigates two approaches for setting total allowable commercial catches (TACCs) and managing the fishery. The first approach, based on the current management system, sets a low base TACC which can be increased in-season based on the results of a resource survey. The second approach sets higher TACCs and closes individual scallop beds when catch rates (CPUE) fall below a specified threshold level.

This report summarises the methods and results of the Coromandel scallop MSE work. The key steps were: discussion with industry members to ascertain their objectives for the fishery; development of an operating model to reflect stock and fishery dynamics; analysis of historical scallop survey and fishery CPUE data to provide a basis for tuning the operating model; and simulations of alternative scenarios for managing the fishery. MSE results were presented to the Shellfish Working Group which requested some additional sensitivity trials and model outputs. These additional analyses are presented in Appendix B. Analyses using alternative dredge efficiency estimates are presented in Appendix C. Alternative rules based on biennial and triennial, rather than annual, surveys are presented in Appendix D.

1.1 Harvest strategy modelling

Previous harvest strategy modelling for northern scallops has followed two approaches: individual-based models including incidental fishing effects to estimate yield per recruit (Cryer & Morrison 1997, Cryer & Parkinson 2006) and population simulations to investigate alternative harvest strategies (Cryer et al. 2003). Results from the yield per recruit analyses form the basis for the $F_{0.1}$ values that are used to estimate current annual yield for the Coromandel fishery.

Experimental estimates of incidental mortality on scallops not caught by dredges and mortality on sub-legal sized individuals that are caught and released were included in an individual-based model to estimate yield-per-recruit and egg-per-recruit under constant fishing mortality rates. These analyses indicated that both mortality factors significantly reduce F-based reference points (e.g. F_{max}, $F_{0.1}$), and that a MLS of 90 mm is a reasonable compromise between optimising yield and maintaining high population fecundity (Cryer & Morrison 1997). Later work including indirect effects of dredging on juvenile mortality (through habitat modification) resulted in even lower estimates of F-based reference points (Cryer & Parkinson 2006). Both of these estimates have been applied in recent survey based stock assessments.

Population simulation models were used to evaluate alternative harvest strategies for northern scallops including: fixed exploitation rates, fixed quotas or base TACCs, applying rotational fishing patterns, and enhancement (Cryer et al. 2003). The population models included stock-recruitment relationships with auto-correlated recruitment and incidental mortality effects acting only on juvenile scallops. No error was assumed in implementing the harvest strategies. In non-rotational fisheries, constant-F strategies outperformed constant catch strategies attaining higher catches at lower biological risk. Rotational fishing provided high catch levels at low biological risk but the high exploitation rates required in the open areas could be uneconomical due to low catch rates (Cryer et al. 2003).

1.2 Fisheries Management

Seasonal commercial catch limits for the Coromandel scallop fishery, managed under the Quota Management System since 2002, are set at a low base level (22 t meatweight) at the beginning of the season. Dredge surveys of the major commercial fishing beds are conducted in May, and biomass estimates from these surveys provide a basis for in-season ACE increases, as warranted. Only beds believed to have scallop densities at commercial fishing levels are surveyed. The fishery management year begins April 1, but the commercial scallop fishery opens July 15 and is closed December 21. Any increased ACE that results from the dredge survey biomass estimate has typically been available in early September. In recent years, only 7 commercial fishing vessels have been operating in the SCA CS fishery.

The minimum legal size (MLS) for Coromandel scallops is currently 90 mm shell length. This MLS was shown to be close to optimal (in terms of yield), given significant incidental mortality effects from the dredge gear (Cryer & Morrision 1997).

There are significant recreational scallop fisheries in the Coromandel area, and these are somewhat separated from commercial fisheries through closure of important recreational beds to commercial fishing (Cryer & Parkinson 2006, Holdsworth & Walshe 2009). Even so, recreational scallop catch in the Coromandel commercial fishing beds may be significant.

1.3 Industry Objectives

Meetings were held with industry representatives in Wellington (March 2, 2009) and Tauranga (April 21, 2009) to discuss industry objectives for the fishery. A number of items that could be investigated within the context of a MSE were identified:

- Increase the base (beginning of season) TACC
- Employ a decision rule for setting TACCs
- Reduce cost or eliminate the annual survey
- Remove constraint of seasons
- Option for higher initial TACC with bed closures when CPUE dropped below a threshold.

The main industry objectives are to ensure high annual catches with low inter-annual variability and to reduce the costs of fisheries management. Catches in the order of 100–110 t (meatweight) are considered a reasonable goal. Industry aspirations are to entrench an alternative approach to managing the commercial SCA CS fishery within a Fishery Plan.

2. THE OPERATING MODEL

The operating model describes the dynamics of the population and the fishery and, for the purposes of the MSE, is taken to represent reality. Often fisheries operating models are based on stock assessment models, which have been fitted to available data. When the assessment models are Bayesian, uncertainty in key parameters is readily captured through their marginal posterior distributions. New Zealand examples of this approach are: rock lobster (Breen et al. 2008) and hoki (Haist et al. 2006). For SCA CS, there is no existing stock assessment model, so the operating model is developed from information in the literature and from analysis of survey and fishery data. Where values for model parameters are uncertain, conservative assumptions have been made. That is, the assumptions adopted favour less productive and less resilient stocks.

Four sub-populations are modelled, representing the major commercial fishing areas of SCA CS: Hauraki Gulf (HG), Mercury Islands (MI), Bay of Plenty (BP), and Barrier Islands plus Colville (BI) (Figure 1). The overall population size is scaled to be of similar magnitude to the Coromandel resource, with sub-populations scaled to reflect the average catch, the average survey abundance, and the scallop bed area for each of these sub-populations. The population dynamics of the sub-populations are essentially independent, that is, there is no dispersal of spat between areas. This is a conservative assumption as dispersal among areas would result in greater resilience to harvesting. Correlation in the magnitude of recruitment among the areas is assumed.

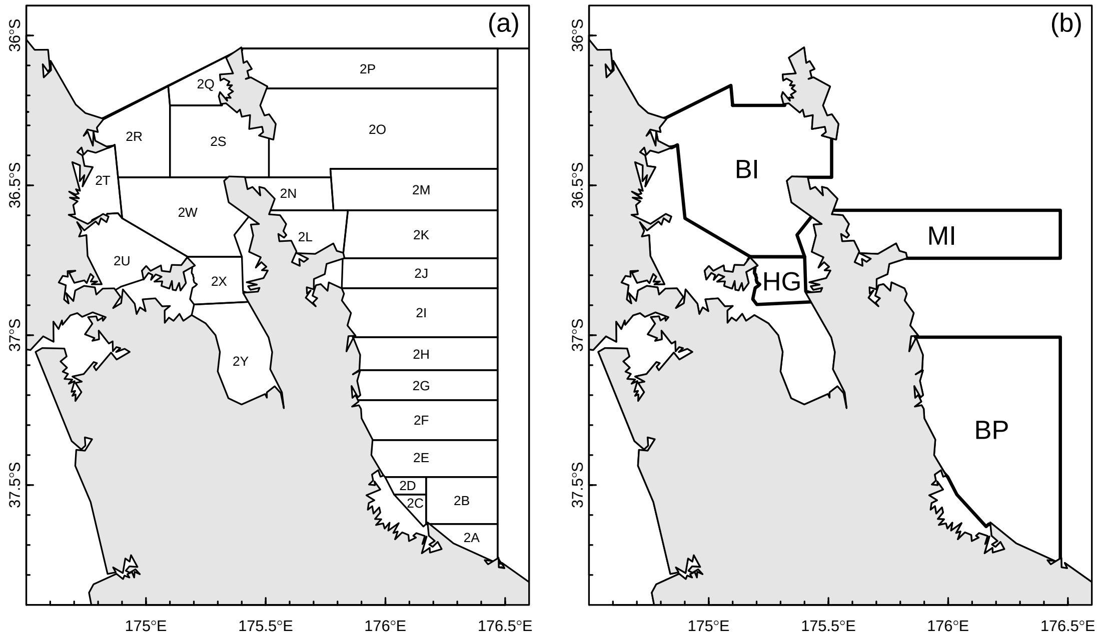

Figure 1: Map of (a) scallop statistical areas in the SCA CS Quota Management Area, and (b) the statistical area groupings assumed for the four sub-populations in the operating model.

The population model tracks the numbers of scallops at length, with length bins from 20 mm to 120 mm shell length in increments of 1 mm. The final length bin accumulates all scallops of 120 mm or greater. The model operates over twelve equal length time steps each year. During the first time step (May 15 – June 14), recruitment and surveys occur. The fishery operates from time steps three to seven (July 15 – December 14), a simplification given the December 21 actual closing date of the fishery. Spawning occurs at the end of time steps six and seven. Natural mortality and growth operate in each time step, assuming constant rates throughout the year.

2.1 Sub-population and bed structure

The structure of the major Coromandel scallop fishing areas has changed over time with the Hauraki Gulf contributing a significant proportion of the total catch until the early 1980s when the Mercury Island area became relatively more important. For the period 1980 – 1991 catch from the Hauraki Gulf represented 33% of the total Coromandel scallop catch. Since then, the proportion has been less than 5%. There have also been changes in the area of scallop beds surveyed in each of the major areas, in particular an increase in the size of the Mercury Islands beds and a decrease in the size of the Hauraki Gulf and Bay of Plenty beds (Table 1). The areas surveyed have generally reflected areas where industry anticipates that commercial densities are available, rather than areas that encompass the scallop populations.

For the MSE simulations the total bed area is set approximately equal to the long-term average of the surveyed area – 190 million square metres – in order to reflect the longer-term productivity of the stock. The Hauraki Gulf and Mercury Islands sub-populations have bed areas similar to their recent average sizes and the Bay of Plenty and the Barrier Islands sub-populations have bed areas similar to their long-term average sizes (Table 1). This distribution of bed area to sub-populations captures the recent importance of the Mercury Islands sub-population to the fishery and the decline in importance of the Hauraki Gulf sub-population. Within each sub-population the total area is separated into distinct beds, with three beds in all areas except for the Hauraki Gulf which has only one bed. The size of individual beds is based on bed areas in recent scallop surveys (Williams 2009, Williams 2008, Williams et al. 2007, Cryer & Parkinson 2006). The number of beds simulated for each sub-population is a compromise between the number of strata surveyed in the area in recent years and the number of scallop statistical reporting areas for the sub-population.

Additional structure is added by sub-dividing each scallop bed into three equal-area sub-beds. The rationale for this structure is that commercial fishery CPUE tends to be higher than expected, given the estimated scallop densities from dredge surveys. The commercial fisheries operate in the parts of the beds where scallop densities are higher, and avoid the low density areas. The simulated sub-bed structure allows this behaviour to be captured for the simulated fisheries.

Recruitment is simulated with 10%, 30% and 60% of the total bed recruitment going to each of the sub-beds. The process is not random, so that each sub-bed always receives a fixed proportion of the total bed recruitment. For a single cohort recruiting to a bed, the variation in cohort density among the sub-beds has a CV of 0.62. That is, random sampling of sub-beds in proportion to their areas (which are equal) would result in a sampling CV of 0.62 for the mean bed density. For scallop dredge surveys since 1991, the average CV of legal sized scallops within beds is 1.01. This is higher than the CV for simulated beds but should be a reasonable approximation to actual scallop beds, given that the simulated sub-beds have simplified structure with homogeneous densities in each sub-bed.

Table 1: Surveyed (average) and simulated areas (million square meters) of scallop beds by sub-population, and simulated areas of individual beds.

	Surveyed			Simulated	
Sub-Population	1991–2008	1991–2002	2003–2008	Total area	Individual bed area
Hauraki Gulf	57	69	30	30	30
Mercury Islands	46	27	71	75	28, 28, 19
Bay of Plenty	65	82	45	60	31, 17, 12
Barrier Islands	22	26	17	25	12, 7, 6
Total	190	204	163	190	

2.2 Recruitment

Trends in annual catch and in the dredge survey biomass estimates indicate correlation among sub-populations and auto-correlation in the time series (Table 2). Although these correlations reflect legal sized scallops, given the high scallop total mortality rates they are also likely to reflect auto-correlation in recruitment within areas and correlation of recruitment among areas. Note that while the correlation for Hauraki Gulf – Mercury Island survey biomass estimates is low for 1980 – 2007, the correlations are much higher when the data is separated into two periods: correlations of 0.55 for 1980 – 1996 and 0.65 for 1997 – 2007.

Scaling of the Coromandel scallop population, and sub-populations within it, is done with parameters that determine the average recruitment to each sub-population (S) in the absence of fishing (R_0^S). This is parameterized with an overall average virgin recruitment (R_0) and parameters representing the fraction of the overall virgin recruitment in each sub-population (f^S):

$$R_0^S = f^S R_0 .$$

Recruitment is modelled with a Beverton-Holt stock recruitment relationship, assuming a steepness of 0.7, following the assumption of Cryer et al. (2003). As those authors point out, a steepness of 0.7 is near the low end of the credible range for scallops. Assuming this value is intended to ensure that the actual populations will be more robust to exploitation than the simulated populations.

Recruitment residuals are log-normally distributed with mean 0 and standard deviation of 0.9. The recruitment residuals are auto-correlated and correlated among the sub-populations, to reflect the empirical correlation structure of the survey biomass and catch history (Table 2). Annual recruitment is given by:

$$R_y^S = \frac{\alpha^S S_{y-1}^S}{\beta^S + S_{y-1}^S} \exp\left(d_y^S - 0.5\sigma_r^2\right),$$

where the stock recruitment parameters $\left(\alpha^S, \beta^S\right)$ are determined by the sub-population specific R_0^S and the specified steepness (0.7), σ_r is the standard deviation of the recruitment residuals, and the annual recruitment deviations $\left(d_y^S\right)$ are given by:

$$d_y^s = \rho^S d_{y-1}^s + \left(1-\left(\rho^S\right)^2\right)\sigma_R\left(\sqrt{r^S}\varepsilon_y + \sqrt{1-r^S}\varepsilon_y^S\right) \qquad \varepsilon_y \sim N\left(0,1^2\right),\ \varepsilon_y^S \sim N\left(0,1^2\right).$$

Simulated values for the sub-population recruitment autocorrelation (ρ^S) and the parameters that determine the degree of recruitment correlation among the sub-populations (r^S) are given in Table 3, as well as the simulated correlations.

Within each sub-population, recruitment to each scallop bed is based on the fraction of the total bed area the bed contains, with annual random variation:

$$R_y^{S,B} = \frac{R_y^S A^{S,B} \exp\left(\varepsilon_y^{S,B}\right)}{\sum_B \left(A^{S,B} \exp\left(\varepsilon_y^{S,B}\right)\right)} \qquad \varepsilon_y^{S,B} \sim N(0,0.2^2)\ ,$$

where $R_y^{S,B}$ is the recruitment to bed *B* of sub-population *S* in year *y* and $A^{S,B}$ is the area of bed *B* of sub-population *S*.

Although spawning occurs year-round, peak spawning is in December (Bull 1988). The operating model has two spawning events occurring at the ends of model periods 6 and 7 (November 14 and December 15), with subsequent recruitment occurring 6 months later (model period 1).

Table 2: Correlation and auto-correlation (A/C) in catch (1980–2007) and survey biomass (1984–2007) estimates among the major Coromandel scallop areas. Catch and survey biomass estimates used in correlation estimates are taken from Williams (2008).

	Catch				Survey biomass (scallops > 95 mm)			
	A/C	Mercury	Plenty	Barrier	A/C	Mercury	Plenty	Barrier
Hauraki	0.57	0.31	-0.09	0.04	0.71	0.20	0.06	0.34
Mercury	0.45		-0.31	0.34	0.82		0.36	0.34
Plenty	0.53			-0.38	-0.02			0.52
Barrier	0.40				0.42			

Table 3: Stock recruitment parameter values and resulting simulated correlation and auto-correlation (A/C) for the major Coromandel scallop sub-populations.

	Stock recruitment parameters				Correlation			
	α^S	β^S	ρ^S	r^S	A/C	Mercury	Plenty	Barrier
Hauraki	4.02E+06	5.18	0.6	0.55	0.57	0.55	0.35	0.24
Mercury	8.44E+07	73.84	0.6	0.55	0.60		0.35	0.22
Plenty	1.88E+07	16.92	0.6	0.20	0.60			0.14
Barrier	2.68E+07	24.17	0.6	0.10	0.58			

2.3 Maturity/Fecundity

Scallop maturation rates are modelled with a logistic function, based on information presented by Williams & Babcock (2005) whose study was conducted in the Hauraki Gulf. They present maturation rates as a function of shell height; these were converted to functions of shell length for this analysis. The resulting values, 50% mature at a shell length of 67 mm and 95% mature at 72 mm, suggest much later maturity than the 100% mature at 60 mm assumed by Cryer & Morrison (1997).

Fecundity is assumed to be proportional to roe weight. The shell length - roe weight relationship is taken from Cryer & Morrison (1997), whose analysis was based on scallops collected in Bumper Cove and Opito Bay in the Mercury Islands. Roe weight (w^r) as a function of length (l),

$w^r = a\, l^b$, where a = 1.821E-14 and b = 4.1717,

was converted from the roe weight – shell height, and shell height – shell length relationships given in Cryer & Morrison (1997, table 8).

2.4 Growth

Scallop growth rates are spatially and temporally variable; growth to 100 mm takes approximately 1.5 years in the Hauraki Gulf and 3 or more years in the eastern Coromandel Peninsula (Cryer & Morrison 1997). Growth rates have been shown to be depth dependent and to have high inter-annual variability (Cryer, pers. comm.). The operating model does not include depth structure so this component of variability is not modelled, but inter-annual growth variability is modelled.

Growth is modelled with a von Bertalanffy growth model with parameters determined such that on average growth to 100 mm takes between 2.2 and 3.3 years for the four Coromandel sub-populations (Table 4, Figure 2). The von Bertalanffy *K* and *Linf* values for the BP and BI growth models are taken from the weekly growth increments estimated by Cryer & Parkinson 2006 from tag-recapture data (Cryer & Parkinson 2006, figure 6). Faster growth is modelled for the HG sub-population and slower growth for the MI sub-population, loosely based on the *K* and *Linf* values assumed by Cryer et al. (2003).

The operating model has scallop recruitment occurring at age 6 months at an average shell length of 30 mm (normally distributed with a variance of 30) for all sub-populations. The von Bertalanffy *t0* parameters are fixed at appropriate values so that the predicted mean size at 6 months was 30 mm.

Growth transition matrices are calculated assuming that growth is normally distributed with means predicted from the growth model and standard deviations (s_l) that are a function of the mean growth increment (I_l) and the length of the time-step (*t*, in fractions of a year).

$$s_l = \sqrt{(2.0t + 0.15I_l)^2 / t} \ .$$

Inter-annual variability in growth is modelled as a random process, assuming only the *K* parameter changes. Alternative growth scenarios were generated by reducing and by increasing the *K* parameter by 0.2 and 0.4. Growth transition matrices are calculated for each growth scenario, and for each sub-population, a random growth transition matrix is selected for each simulated year.

Incidental fishing effects on growth are also modelled. When fishing mortality rates exceed 0.2 or 0.4 in a time step, the growth *K* parameter is reduced by 0.1 and 0.2, respectively.

Table 4: *Baseline* growth parameters for the four simulated Coromandel scallop sub-populations, and age at 100 mm for the *baseline* and alternative growth scenarios ($K \pm 0.4$).

	HG	MI	BP	BI
Linf	110	120	110	110
K	1.20	0.5	0.75	0.75
t0	0.23	-0.08	0.08	0.08
Age at 100 mm (*baseline*)	2.2	3.5	3.3	3.3
Age at 100 mm $(K+0.4)$	1.8	2.2	2.3	2.3
Age at 100 mm $(K-0.4)$	3.1	8.0	6.4	6.4

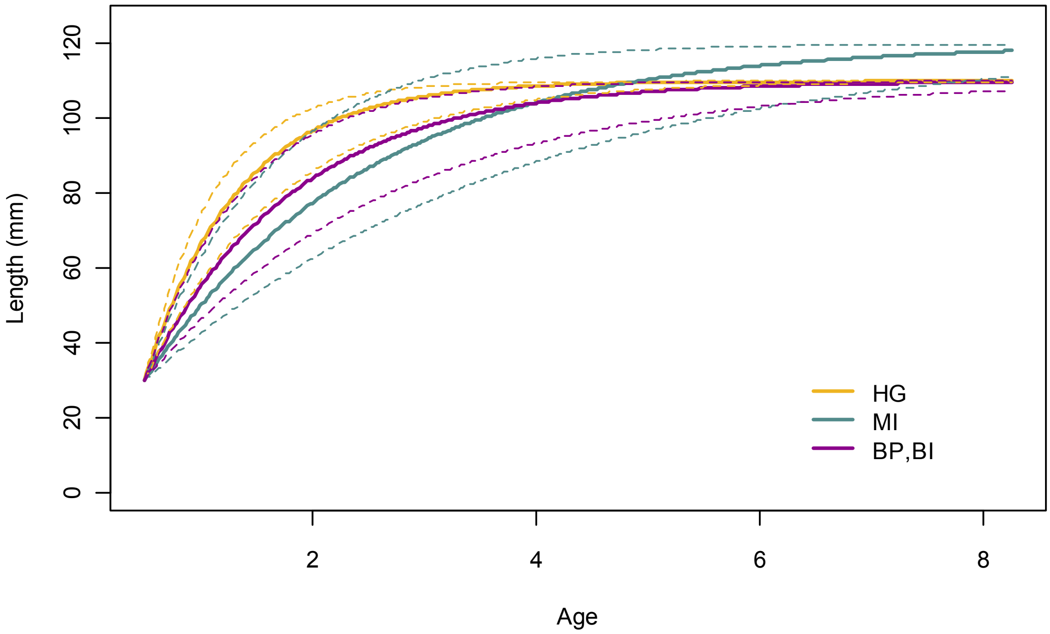

Figure 2: Growth curves modelled for the for Coromandel scallop sub-populations. The solid lines reflect *baseline* growth for the Hauraki Gulf (HG), Mercury Islands (MI), Bay of Plenty (BP) and Barrier Island (BI) sub-populations. The dashed lines show the maximum range of the growth curves used to generate growth transition matrices (*K*±0.4).

2.5 Mortality

We assume an instantaneous annual natural mortality rate of 0.5, a value consistent with that used in the existing annual stock assessments (Williams 2009). For each time step, natural mortality is modelled as lognormal with a standard deviation of 0.15:

$$M_{y,t}^{S} = \frac{0.5}{12}\exp\left(\varepsilon_{y,t}^{S}\right) \qquad \varepsilon_{y,t}^{S} \sim N\left(0, 0.15^2\right),$$

where $M_{y,t}^{S}$ is the natural mortality rate for sub-population *S* in time step *t* of year *y*. Additionally, catastrophic natural mortality events that result in a mortality rate of 1.0 for the time step are modelled with an annual probability of 0.02. Catastrophic mortality events are independent among sub-populations so that each sub-population has probability of 0.02 that a catastrophic mortality event occurs in any year. A sensitivity trial is included where the probability of catastrophic mortality events is increased to 0.05.

2.6 Dredge Efficiency

Dredge efficiency (for surveys and the fisheries) is modelled parametrically with logistic curves, based on data presented in Cryer & Parkinson (2006, figure 5). Re-analysis of the scallop dredge efficiency data by Bian et al. (2010) suggests considerable variability in dredge efficiency, and this is incorporated in the operating model by randomly selecting from 72 dredge efficiency curves. Dredge efficiency at length l (s_l) is modelled as:

$$s_l = \begin{cases} m\left(\exp\left(1+{}^{-\ln(19)}\!/_{a}\,(l_l - c + b)\right)^{-1} + d\right) & \text{for } l \le c \\ m\left(\exp\left(1+{}^{-\ln(19)}\!/_{a}\,(-l_l + c + b)\right)^{-1} + d\right) & \text{for } l > c \end{cases}$$

where

$$m = g\left(\exp\left(1+{}^{-\ln(19)b}\!/_{a}\right)\right)$$

where g is the maximum dredge efficiency, c is the length with the maximum dredge efficiency, a and b modify the curvature of the logistic curve, and d is a constant added to the function so that dredge efficiency doesn't approach zero. Based on Cryer & Parkinson (2006, figure 6), a maximum dredge efficiency of 0.39 at a length of 105 mm with efficiencies of about 0.2 at lengths of 90 mm and 120 mm was selected to represent the basic dredge efficiency (parameters shown in Table 5). A range of values around the base set was selected to generate a range of potential dredge efficiency curves (Table 5). All combinations of the parameter values shown in Table 5 were used to generate 72 potential dredge efficiency curves (Figure 3). A *baseline* dredge efficiency curve is calculated as the mean efficiency at length across the 72 curves (Figure 3).

Table 5: Dredge efficiency model parameter values for the "base" set and the range of values used to simulate dredge efficiency variants.

Parameter	Base values	Simulated range
g	38	30, 38, 46
c	105	98, 105, 112
a	20	15, 25
b	15	10, 20
d	0.01	0.005, 0.02

The dredge efficiency curve predicts the proportions-at-length that are selected by the gear. These values are used directly in calculations of numbers-at-length in survey catches but are converted to instantaneous rates for use in the fishing mortality equations:

$$d_l = -\left(\ln\left(1 - s_l\right)\right) \ .$$

This reformulation of the dredge efficiency results in proportions selected at length equivalent to the s_l when the fishery fishes 100% of an area (and there is no natural mortality during the fishing interval).

For simulated surveys, a random dredge efficiency curve is selected for each bed surveyed. Conversion of simulated surveys to the abundance estimates, upon which in-season ACE adjustments are based, assumes the *baseline* dredge efficiency. For simulated fisheries, a random dredge efficiency curve is selected for each sub-bed fished in each time period.

Sensitivity analyses were conducted by assuming both higher and lower values for the fishery and survey dredge efficiency curve. The alternative dredge efficiencies were based on increasing or decreasing the values of the maximum efficiency (g) in Table 5 by 10. When conducting the sensitivity trials, fishing mortalities and survey efficiencies were based on the alternative dredge efficiency but conversion of simulated surveys to the abundance estimates, upon which in-season ACE adjustments were based, assumed the *baseline* dredge efficiency.

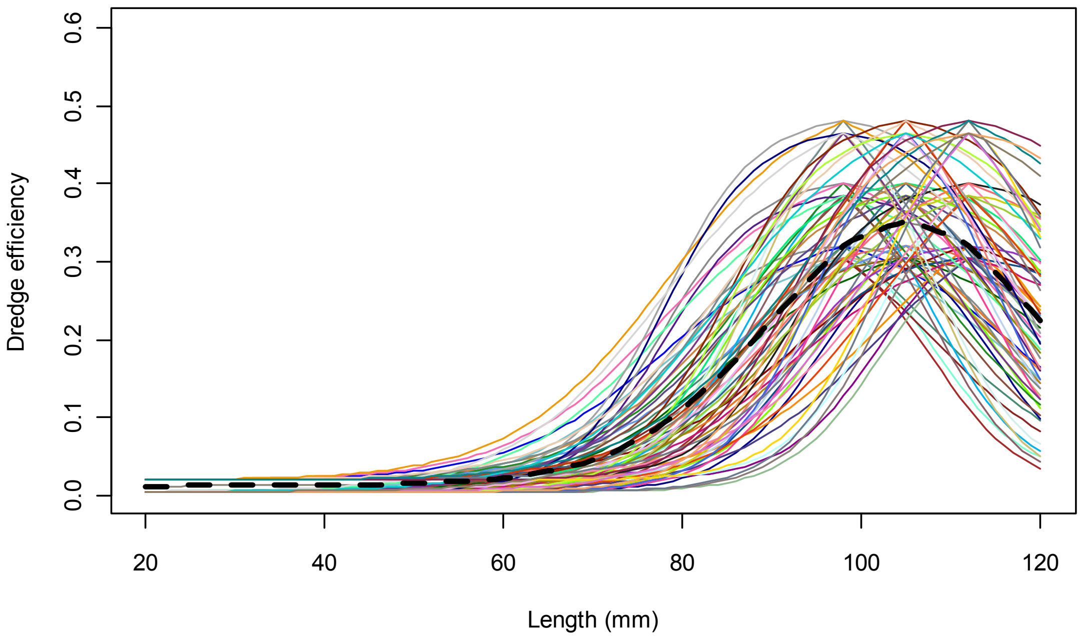

Figure 3: The simulated range of dredge efficiency curves used in the operating model. The black dashed line shows the *baseline* dredge efficiency calculated as the mean efficiency-at-length across the 72 alternative curves.

2.7 Incidental fishing mortality

Incidental mortality has been shown to result from the dredge passing over scallops but not catching them, and from release of scallops caught by the gear and returned to the water (Cryer & Morrison 1997). Mortality rates were higher for scallops retained by the dredge and released than for scallops that were missed by the dredge. The published values for incidental fishing mortality effects are assumed in the operating model (Table 6). The operating model assumption is that all scallops above the minimum legal size that are caught, are retained.

A sensitivity analysis that assumes that the incidental fishing mortality effects are 50% higher than the values estimated by Cryer & Morrison (1997) is also conducted.

Table 6: Mortality rates for scallops passed over but missed by the dredge and for scallops caught by the dredge and released, by scallop shell length (from table 7, Cryer & Morrison 1997).

Shell length (mm)	Scallops missed	Scallops released
20 – 79	0.007	0.139
80 – 95	0.288	0.206
95++	0.250	0.521

2.8 Recreational fisheries

In the Coromandel scallop quota management area, recreational fisheries occur in both commercial scallop fishing areas and in areas closed to commercial fishing. The recreational fishing season runs from September through to March and the minimum legal size is 100 mm. Recreational catch of Coromandel scallops has been estimated through a number of programmes, but estimates from diarist surveys are not believed reliable (Williams 2008). A ramp survey, conducted in 2007, estimated 23.9 t (greenweight) of scallops were caught in the Coromandel scallop fishery from December through February (Holdsworth & Walshe 2009).

The 2007 ramp survey provided detailed information on a sub-set of the estimated scallop catch that presented gear (dive or dredge) and inside/outside commercial closed area information. For the detailed data, 93% of the scallop catch was taken by divers, and 17.4% was taken in areas not closed to commercial fishing (Holdsworth & Walshe 2009). Thus, the three month estimate of scallop catch in the commercial fishing areas is 4.15 t. Diarist survey data suggests that 69.3% of the annual scallop catch is taken in the period December through to February, so an annual estimate of scallop recreational catch in commercial areas is 5.99 t. Holdsworth & Walshe (2009) report that 75% of the surveyed recreational scallop catch was taken from the Mercury Islands. Surveys were not conducted in Waiheke, Great Barrier, Waihi, Papamoa, or Motiti, so there is potentially additional recreational scallop catch in commercial areas not covered by the ramp survey.

For the MSE we assume an annual recreational catch of 8 t (greenweight) in the Coromandel commercial fishing areas. Of this, we assume that 4.5 t comes from MI (75% of 5.99 t), and arbitrarily that 0.5 t comes from HG and 1.5 t from each of BP and BI. The recreational fishery is treated as if occurring in a single time step (15 December to 15 January), with an MLS of 100 mm, and assuming full selectivity (no dredge efficiency).

2.9 Conversion metrics

Based on data in table 4 of Cryer & Parkinson (2006), a normal distribution was assumed for the relationship between greenweight and meatweight, with a mean recovery of 12.5% and standard deviation of 2.0.

The relationship between shell length and greenweight is taken from table 8 in Cryer & Morrison (1997) and a minimum legal size (MLS) at 90 mm shell length is simulated with the fishery retaining all scallops at or above the MLS.

2.10 Simulated Surveys

For decision rules based on surveys, annual surveys that sample all scallop beds with an average density of legal sized scallops greater than 0.06 per m^2 are simulated, assuming perfect knowledge of bed densities. The number of scallops caught in the survey is adjusted for dredge efficiency, with growth and natural mortality applied to generate a pre-fishery estimate of the biomass of legal sized scallops. The average sub-population growth and an annual natural mortality rate of 0.5 are assumed in the calculations. Surveys are conducted by randomly selecting one of the 72 dredge efficiencies for each bed surveyed and the *baseline* dredge efficiency is used to convert survey results to total numbers. For the *dredge efficiency* sensitivity trials, the surveys are conducted with the alternative dredge efficiencies (either higher or lower) and converted to total numbers assuming the *baseline* dredge efficiency. Finally, lognormal random error is applied to the estimate of legal sized scallop pre-fishery biomass (S_y):

$$S_y = S'_y \exp\left(\varepsilon_y - 0.5\left(0.3\right)^2\right) \qquad \varepsilon_y \sim N\left(0, 0.3^2\right)$$

where the S'_y incorporate the error from growth and natural mortality assumptions.

2.11 Simulated Fisheries

Currently seven fishing vessels operate in the Coromandel scallop fishery. The fishery is open for five days per week and daily catch limits apply, by agreement of the participants. Each fisher is given a daily catch limit based on their annual catch entitlement divided by the expected number of fishing days for the season (approximately 100).

Fisheries are simulated by allocating fishing effort (hours) to the sub-beds on the basis of the scallop density (legal sized scallops) in the sub-bed. For each time step the sub-beds are fished in order of their density until either the TACC is taken or the maximum number of hours for the time step is reached. An additional constraint is applied in that only one fifth of the TACC can be taken in any time step, consistent with the catch spreading implemented by the fishery. If there are shortfalls in the catch in one month, these can be made up in following months. The exception to this constraint is for the *Survey* based rules in the first month of the fishery. In that case the full *baseTACC* can be taken in the first time step. The simulated maximum catch that can be taken in each time step is termed *maxCatch*.

Each of the 7 fishing vessels is assumed to operate with a 2 m wide dredge fishing at an average speed of 2.54 nautical miles per hour. Thus, 9408 square meters of scallop bed is fished for each vessel-hour towed. The assumed 2 m dredge width is consistent with the dredges used by the majority of the Coromandel scallop fleet (see Section 4.1). The average fishing speed is based on logbook data collected during the 2009 Coromandel scallop fishery (see Section 4.1).

For each time step, a maximum of 50% of each sub-bed can be fished. The maximum fishing effort per time step is based on 22 fishing days and a maximum of 9 hours fishing per day, resulting in 1386 fishing hours per time step for the 7 vessel fleet. The procedure for each time step is:

1) Sort sub-beds by density of legal-sized scallops.
2) Begin with 1386 hours of fishing effort.
3) Step over sub-beds in descending order of density (if *LimitTACC* rule, only beds that have not been closed).
    a. For *LimitTACC* rules calculate CPUE (catch in one hour fishing) and determine if bed is closed. This is intended to mimic test fishing in a bed that has not been fished.
    b. Calculate hours fishing in sub-bed (fish maximum of 50% of bed area or until hours for time step are zero).
    c. Calculate fishing mortality rate and catch for sub-bed (see below).
    d. Return to b) and reduce hours if *maxCatch* for time step exceeded.
    e. Catch is taken.
    f. For *LimitTACC* rules calculate CPUE (sum of catch/sum of hours fished, with error) and determine if bed is closed.
    g. Decrement fishing hours remaining.
    h. If there are fishing hours remaining and catch remaining, return to step 3.

For each sub-bed, the fraction (*f*) of the area fished is given by:

$$f = \frac{9\,408 \bullet hrs}{B},$$

where *hrs* is the hours fished in the sub-bed and *B* is the area of the sub-bed. The fishing mortality rate for landed scallops of length *l* $\left(F_l^C\right)$ and the incidental fishing mortality rate for scallops missed or caught and released $\left(F_l^I\right)$ is given by:

$$F_l^C = f d_l L_l$$

$$F_l^I = f\left(d_l\left(1-L_l\right)r_l + \left(1-d_l\right)m_l\right)$$

where d_l is the dredge selectivity (efficiency) for scallops of length *l*,
L_l is a binary variable that is equal to 0 for scallops less than legal size and 1 for scallops equal to or above legal size,
r_l is the mortality rate of scallops caught and released (see Table 6),
m_l is the mortality rate of scallops passed over but missed by the dredge.

The catch of legal sized scallops in the sub-bed during the time step is then given by:

$$C_l = \frac{F_l^C}{F_l^C + F_l^I + M}\left(1-\exp\left(-F_l^C - F_l^I - M\right)\right)N_l$$

where C_l is the catch (landings) of scallops of length *l*,
M is the natural mortality rate (for the time step), and
N_l is the number of scallops of length *l*.

The instantaneous form of the catch equations used accounts for the decline in scallop density through a time step as a result of fishing.

CPUE is calculated as the ratio of catch to hours fished in each sub-bed, with random error added:

$$CPUE = \frac{\sum_l C_l}{hrs}\delta \qquad \delta \sim \mathrm{N}\left[1, 0.2^2\right]$$

A sensitivity trial is conducted that assumes an alternative fishing pattern. For those simulations, no knowledge of the density of scallops in the individual fishing beds is assumed. The sequence for fishing scallop beds is random, but the sub-beds within a bed are fished in order of their density. This sensitivity trial represents an extreme relative to the *baseline* simulations which assume perfect knowledge of bed densities.

3. DECISION RULES

Two types of decision rule are investigated. For the first class of decision rule, the *LimitCPUE* rule, a TACC is set (in meatweight) for the year and the fishery continues with individual scallop beds closed when the limit CPUE level is breached on the bed. Potentially all the scallop beds can be closed before the TACC is achieved. For the second class of decision rule, the *Survey* rule, a base TACC is set but can be increased based on the results of a survey. The survey takes place in May; the fishery opens in July and any increase in the TACC occurs in the second time step of the fishery (August 15).

The *LimitCPUE* class of decision rules have two control parameters: the TACC and the value of CPUE below which scallop beds are closed (*CPUElim*). The range in parameter values investigated in this analysis is shown in Table 7.

The *Survey* class of decision rules also have two control parameters: the base TACC (*Base TACC*) and the parameter that controls how the TACC increases based on survey results (*Fmult*). The revised TACC is calculated as:

$$TACC_y = Fmult \cdot S_y$$

where S_y is the estimated biomass of legal sized scallops from the survey in year *y*. The range in parameter values investigated is shown in Table 7. Note that the existing annual SCA CS assessments have calculated potential TACCs from the survey-based pre-fishery biomass estimates using a more complex CAY formula and instantaneous estimates of reference fishing mortality rates ($F_{0.1}$). Projections for two $F_{0.1}$ levels are generally presented in the assessment (e.g. Williams 2008); one that accounts for direct incidental effects of fishing such as reduced growth and incidental fishing mortality ($F_{0.1}$ = 0.431) and one also includes indirect incidental effects related to reduced habitat heterogeneity($F_{0.1}$ = 0.271). Translated to exploitation rates, like the *Fmult* parameter used here, the $F_{0.1}$ values translate to 0.32 ($F_{0.1}$ = 0.431) and 0.22 ($F_{0.1}$ = 0.271).

Table 7: Decision rule parameter values for the *LimitCPUE* and *Surve*y classes of decision rules. Note that TACCs are expressed in meatweight tonnes while CPUE is greenweight kg in an hour of fishing.

	LimitCPUE		*Survey*
TACC (t)	80, 90, 100, 110, 120	*Fmult*	0.1, 0.15, 0.2, 0.25, 0.3
CPUElim (kg/hr)	40, 50, 60, 70	*BaseTACC (t)*	22, 32, 42, 52

3.1 Performance Indicators

A number of summary statistics are calculated for each simulation trial to summarize rule performance relative to objectives.

Performance indicators related to safety considerations are based on the Harvest Strategy Standard and are calculated for both the aggregate population and for each sub-population. These include: the mean and median spawning stock biomass (SSB) relative to virgin SSB (B_0), and probabilities that SSB is below 10% and below 20% of B_0 .

Numerous indicators related to fishery performance are calculated. These include: the means and distributions of catch (in meatweight and greenweight), the means and distributions of CPUE, the probability that the TACC is caught, the probability that all scallop beds are closed, and the probability that the maximum number of fishing hours limits the taking of the full TACC.

Finally, some summary statistics are calculated to assess results of the simulations against the actual SCA CS resource. These include: the mean number of scallops caught in the surveys, the mean density of legal sized scallops, and the mean number of scallop beds fished each year.

For each simulation trial, the sub-populations are initiated at the unfished deterministic equilibrium level and then fished with the specified decision rule for 3010 years. Summary statistics are calculated from the final 3000 years of the simulation.

4. FISHERY AND SURVEY DATA

4.1 Commercial fishery CELR

An extract of the Ministry's catch effort data base (Warehou) was obtained to ascertain characteristics of the Coromandel scallop fishery. Catch Effort Landing Return (CELR) data were available for 1995 – 2008, and the subset of observations from the seven fishing vessels operating in the 2008 fishery was analyzed. Most of the fishing vessels reported their estimated catch in greenweight but one vessel, and occasionally a second vessel, reported catch in meatweight. Landings data were used to adjust the catch estimates to greenweight for all vessels.

Mean annual CPUE is highly variable, ranging from a low of 41 kg/hr in 1996 to a high of 387 kg/hr in 2005 (Table 8). Over all years, the mean catch rate was 135 kg/hr. The number of scallop statistical areas fished each year was also variable, ranging from 2 to 8.

The CPUE data can be also be used to calculate catch rates in terms of biomass of scallops caught per square metre dredged for comparison with survey data. For these calculations we assume an average towing speed of 2.54 knots (see Section 4.2) and average dredge width of 2 m to convert hours towed to area dredged. Summarized by sub-population and year, catch rates in terms of g/m^2 ranges from 1.0 for the HG subpopulation in 1995 to 35.7 for the BI subpopulation in 2005 (Table 9)

Table 8: Mean CPUE (kg/hr) by scallop statistical reporting area and year for the Coromandel scallop fishery. Data are based on the seven selected fishing vessels and include only areas with 5 or more data records (i.e. days fishing reported).

Sub-Pop	Stat. area	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
BP	2A					54	42	62	63	107	139				
BP	2C		41	79			54		42						196
BP	2D									180	228				
BP	2E								61	174	157				
BP	2F								46	112					
BP	2G										226				
BP	2H		94								143				
MI	2K													79	
MI	2L	75	90	79	47	41	54	61	66	151	240	318	275	149	197
BI	2R		151	148		82		133	82	154	188	324	291	143	171
BI	2S	117													
BI	2W		105	130	120					145	209	387	262	154	
HG	2X				96					102					
Avg.		89	103	92	49	63	46	89	62	154	207	319	276	145	196

Table 9: Estimated mean catch rate (g/m^2) of legal sized scallops by sub-population in the Coromandel scallop fishery. Estimates are calculated based on the total fishing time, an average towing speed of 2.54 knots and dredge width of 2 m, and the catch of legal sized scallops.

Sub-Pop	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
HG				10.2					10.8					
MI	7.9	9.6	8.4	5.0	4.3	5.7	6.5	7.0	16.0	25.5	33.7	29.2	15.3	20.9
BP		7.2	8.4		5.7	4.5	6.5	6.4	17.3	18.9				20.8
BI	12.5	15.1	15.5	12.8	8.7		14.1	8.7	15.6	20.9	35.7	29.9	15.8	18.1

4.2 Commercial fishery logbook programme

For the 2009 Coromandel scallop fishery, a logbook programme was implemented to obtain detailed information from the fishery. The logbook data included: daily catch rates by fishing bed (estimated catch and landed catch weight); fishing conditions including vessel speed, wind direction and speed, swell speed and direction; scallop meat recovery rates; and proportion of catch above the MLS. The logbook data was compiled on a weekly basis, and summaries of catch rates by fishing bed developed to demonstrate industry's ability to collect data to manage the fishery using CPUE limits for closing scallop beds.

Eleven scallop beds were fished in the 2009 Coromandel scallop fishery, although one bed (Otama) had only a small amount of exploratory fishing (Table 10). CPUE was variable among the scallop beds, and tended to decrease over the season in some areas (e.g. Black Jack and Mercury Cove, Table 11). The fishery was closed early in mid-November before the full ACE was taken because CPUE had dropped below levels acceptable to the fishers.

The average towing speed in the 2009 Coromandel scallop fishery was 2.54 knots, varying somewhat among vessels (Table 12). Of the seven vessels in the fishery, the dredge width is 2 metres for four of the vessels with one vessel having a smaller dredge and two vessels having larger dredges (Table 12).

Table 10: Hours fished by fishing bed and week from logbook data collected from the Coromandel scallop fishery in 2009.

Week	Black Jack	Bumper Cove	Colville	Kennedy Bay	Koropuke	Little Barrier	Mercury Cove	Opito	Otama	Sarah's Gully	Three mile
1						83.3					
2						89.7					
3	93.7	5.8			11.8		10.0			2.0	
4		38.5			8.0		30.3				
5	12.8	26.8			6.5		44.0			5.0	34.3
6						120.9					
7						180.1					
8	40.5	42.8		54.0	17.0		44.8				9.0
9	74.0	32.5									59.0
10	97.8	50.5		8.5				7.3		6.0	45.5
11	50.3	15.0			25.3			84.5		9.5	14.0
12	58.0	6.0	66.7	40.3	7.0		2.5				20.0
13	125.8	16.0		8.5	14.0				5.5	8.0	11.0
14	52.6			37.3	69.0		4.5	32.8	2.0	23.8	
15	78.3	11.0		8.0	49.8		6.0	17.0		6.0	
16	32.8			15.3	67.8						
Total	716.4	244.8	66.7	171.8	276.0	474.0	142.0	141.6	7.5	60.3	192.8

Table 11: CPUE (kg greenweight/hours fished) by fishing bed and week from logbook data collected from the Coromandel scallop fishery in 2009.

Week	Black Jack	Bumper Cove	Colville	Kennedy Bay	Koropuke	Little Barrier	Mercury Cove	Opito	Otama	Sarah's Gully	Three mile
1						258.2					
2						268.2					
3	110.1	101.4			66.5		240.9			90.5	
4		91.0			103.5		126.9				
5	126.6	88.4			73.0		136.2			88.0	99.6
6						175.5					
7						155.4					
8	93.9	69.0		96.8	49.0		98.4				73.1
9	86.4	68.1									93.2
10	73.6	70.6		86.6				116.1		63.5	79.4
11	90.5	51.6			80.7			90.9		83.0	92.7
12	101.4	46.3	147.1	83.6	82.6		103.0				52.9
13	101.4	67.5		100.6	74.1				48.7	122.0	61.6
14	95.1			96.6	68.2		87.7	75.9	67.5	102.9	
15	67.8	60.5		99.0	78.4		75.2	74.9		39.0	
16	75.3			95.5	68.9						

Table 12: Dredge width (m) and average tow speed (knots) for the seven fishing vessels operating in the Coromandel scallop fishery in 2009.

	A	B	C	D	E	F	G
Tow speed	2.1	2.4	2.6	2.8	2.7	2.4	2.8
Dredge width	1.5	2.4	2.0	2.0	2.0	2.3	2.0

4.3 Survey data

An extract of the scallop survey database was obtained, and the Coromandel dredge survey data summarised for use in comparison and validation of the MSE operating model.

Summaries of the 2005–2008 survey data have been reported in stock assessment documents and can be used to validate the database summaries reported here. The total areas surveyed agree between the published and database extract, except for the 2005 HG survey which is slightly higher for the database extract (Table 13).

For the database extract, scallop densities were calculated by summing scallops (greater than or equal to 90 mm) and area dredged across stations within a scallop bed after adjusting for the fraction sampled. Then, sub-population density estimates were calculated by weighting bed densities by their relative sizes. Estimates of density, not adjusted for dredge efficiency, are similar for the database extract and the published values, although generally not in complete agreement (Table 14).

Scallop survey abundance estimates (product of density and area) are adjusted to population estimates based on dredge efficiency assumptions. For the scallop stock assessments, different dredge efficiency assumptions are made for sand and silt substrates, but for the MSE operating model a single dredge efficiency is used. Substrates in the Coromandel scallop area are primarily sand, except for HG and Colville which are primarily silt. The database estimates of adjusted scallop abundance and density used here were calculated using the operating model *baseline* dredge efficiency. For the HG sub-population, the database adjusted density estimates are higher than published estimates while for other areas the estimates are somewhat lower. The differences are not large, which provides some support that the operating model *baseline* dredge efficiency is similar to that used in the annual stock assessments.

Mean density of legal-sized scallops from the survey (g/m^2, Table 15) are compared with fishery density estimates in Figure 4. In general, density estimates from the fisheries are higher than those from the survey. This is not surprising, given that the fishery will tend to operate in beds and areas within beds that have higher densities, unlike the survey which samples the beds randomly. Overall there is reasonable agreement between the fishery density estimates and those from the scallop dredge survey.

5. MSE RESULTS

5.1 Equilibrium dynamics

Equilibrium dynamics are modelled to determine the productivity characteristics of the simulated population. Simulations are either deterministic or stochastic (in terms of recruitment variation) and stochastic simulations include variation in natural mortality. Yield and fishery-induced mortality, scaled to the MSY, are shown in Figure 5. MSY is attained at annual Fs of 0.35 and 0.4 for the stochastic and deterministic simulations, respectively. These results are in line with those found by Cryer & Morrison (1997). When fishing at F_{msy}, fishing induced incidental mortality is almost equal to MSY. That is, if incidental fishing mortality could be eliminated MSY would almost double.

Table 13: Estimated mean density (g/m^2) of scallops >=90 mm (unadjusted) from the scallop dredge survey by sub-population.

Sub-Pop	1991	1992	1993	1995	1996	1997	1999	2001	2002	2003	2004	2005	2006	2007	2008
HG	0.23	0.74	0.13	0.10	0.45	6.60	0.30	0.22	3.57	3.92	7.42	4.28		2.41	
MI		9.40	7.15	3.58	7.89	8.44	2.34	1.97	4.20	7.29	25.95	29.31	27.78	18.34	16.34
BP			5.62	3.15	1.50	1.07	0.57	2.69	4.23	11.09	6.60	5.87	2.53	4.70	1.57
BI		2.72	1.54	4.99	5.52	6.98	0.69	6.38	6.43	11.19	4.58	17.29	41.24	20.82	7.41

Table 14: Coromandel scallop dredge survey area surveyed (million square metres), unadjusted density of legal sized scallops (>= 90 mm), and density of legal sized scallops adjusted for dredge efficiency from published stock assessment reports (Williams 2009, Williams 2008, Williams et al. 2007, Cryer & Parkinson 2006) and from the database extract for the current analyses, and the ratio of the two sets of estimates.

	Published				Database extract				Database: published ratio			
Area M m^2												
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
HG	24.6		14.9		26.7		14.9		1.09		1.00	
MI	84.2	88.6	88.3	72.9	84.2	88.7	88.3	72.9	1.00	1.00	1.00	1.00
BI+Col	15.2	11.8	12.9	11.8	15.1	11.8	12.8	11.8	1.00	1.00	1.00	1.00
BP	49.8	59.3	59.3	59.3	49.8	59.3	59.3	59.3	1.00	1.00	1.00	1.00
Unadjusted density												
HG	0.054		0.034		0.050		0.029		0.93		0.85	
MI	0.354	0.289	0.191	0.182	0.305	0.289	0.179	0.181	0.86	1.00	0.94	0.99
BI+Col	0.170	0.393	0.201	0.092	0.169	0.401	0.213	0.080	0.99	1.02	1.06	0.88
BP	0.063	0.026	0.054	0.018	0.062	0.027	0.054	0.018	0.99	1.04	1.00	1.03
Adjusted density												
HG	0.149		0.093		0.176		0.107		1.18		1.15	
MI	1.430	1.161	0.695	0.805	1.024	0.971	0.587	0.638	0.72	0.84	0.84	0.79
BI+Col	0.657	1.433	0.704	0.331	0.558	1.348	0.741	0.286	0.85	0.94	1.05	0.86
BP	0.256	0.111	0.251	0.085	0.208	0.093	0.193	0.066	0.81	0.84	0.77	0.78

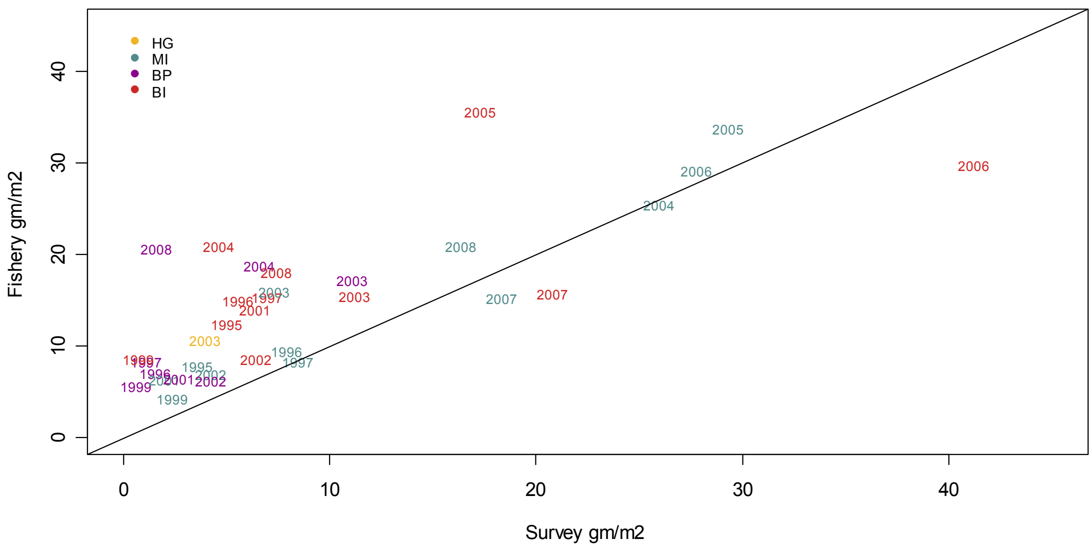

Figure 4: Comparison of catch rates in terms of g/m^2 from the Coromandel scallop fishery and survey. The solid line shows the 1:1 comparison.

When fishing at F_{msy} spawning stock biomass is 33% of the virgin level and the probability of stock biomass being below 20% B_0 is 7.5% for the deterministic simulations. For the stochastic simulations, stock biomass is 28% of the virgin level and the probability of stock biomass below 20% B_0 is 30% when fishing at MSY.

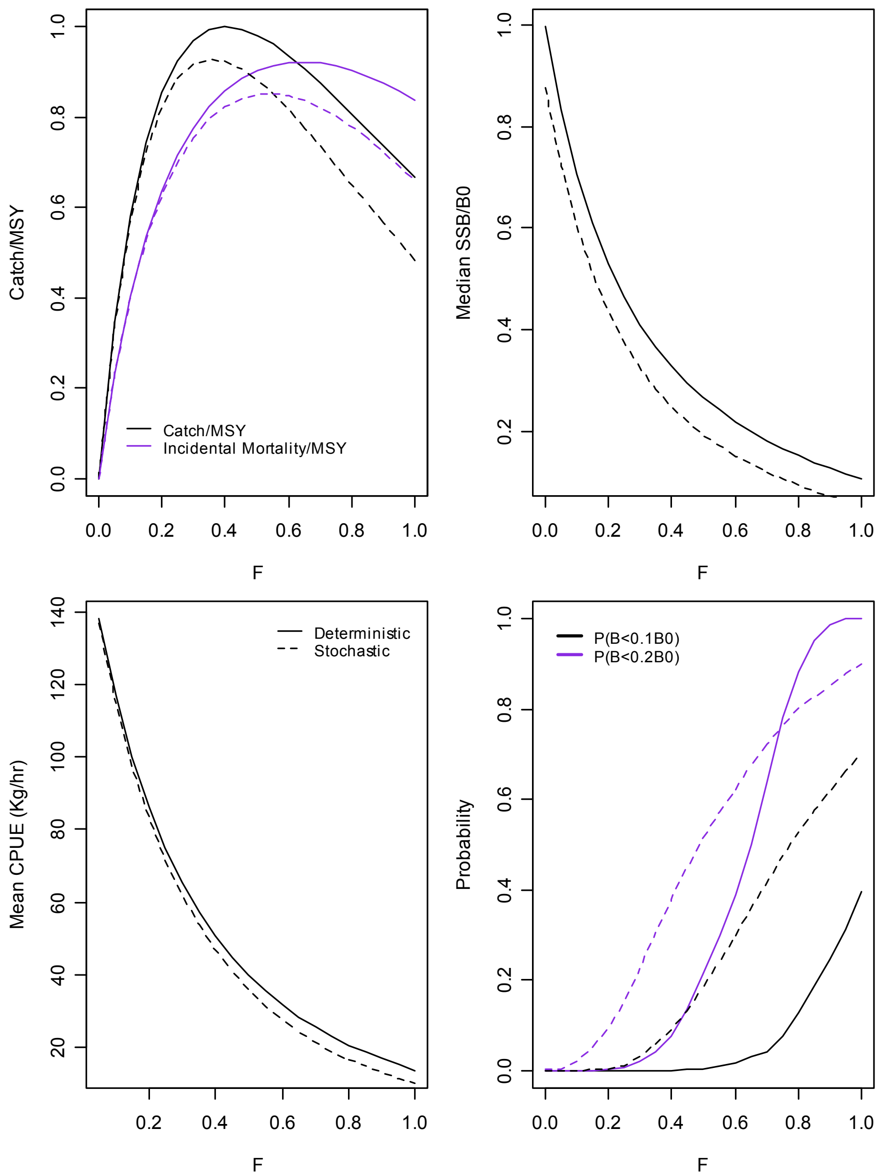

Figure 5: Results from deterministic (solid lines) and stochastic (dashed lines) simulations at fixed fishing mortality (F) values: Catch relative to MSY and incidental mortality relative to MSY; Spawning stock biomass relative to B_0; catch rate (CPUE) in kilograms per hour; and probabilities of stock biomass falling below 10% and 20% B_0.

5.2 Tuning the operating model

Tuning the operating model to reflect Coromandel scallop dynamics involved three steps: specifying the bed area for each sub-population, finding an R_0 value that produced yields and catch rates similar to the long term average for the fishery, and finding the proportion of R_0 recruiting to each sub-population (f^S) so that the density of legal sized scallops was similar to survey estimates and the average proportion of the catch from each sub-population was similar to that obtained by the commercial fishery.

As described in Section 2.1, total area was set equal to the historical average of annual surveyed bed area. Historical catch and survey data suggest a shift in areas of abundance with MI becoming more important relative to HG. The bed areas for each sub-population were set such that BP and BI were similar to the longer term average and HG and MI were similar to recent average bed sizes. Using an equilibrium model, alternative proportions of the total recruitment (R_0) were evaluated to approximate historical catch splits among the sub-populations $\left(f^{HG} = 0.3, f^{MI} = 0.63, f^{BP} = 0.14, f^{BI} = 0.20 \right)$.

Fishery exploitation rates, based on catch divided by survey biomass, suggest an average exploitation rate of about 30% for the period 1995–2007 (Table 16). Estimated exploitation rates for earlier years (1980–1994) are higher; however those estimates are biased because not all scallop beds were surveyed. Average historical exploitation rates are likely to be in the range of 30–40%.

With scallop bed areas and proportions of R_0 for each sub-population fixed, operating model simulations were conducted at a range of R_0 values and survey-based decision rules with *Fmult* values ranging from 0.08 to 0.41. Average catch and average CPUE from these runs were compared with historical average catch (740 t greenweight, 1980–2007) and CPUE (134.5 Kg/hr, 1995–2007). Results suggest that a ln(R_0) of 18.6 is most consistent with the historical data (Figure 6). This R_0 should generate a simulated population of similar magnitude to the actual population. A sensitivity trial is conducted assuming a lower R_0 value (ln(R_0) = 18.4).

For the *Survey* decision rule simulations with $\ln\left(R_0\right) = 18.4$ and *Fmult*=0.3, densities of legal sized scallops in each of the sub-populations are in general agreement with survey values although for the MI and BI sub-populations they are somewhat lower than the longer-term historical averages (Table 16). Increasing the proportion of the total recruitment to these areas increases the simulated scallop density, but also increases the proportion of the total catch for the areas. The proportion of the catch taken from each sub-population in the simulations is similar to that of the actual fishery (Table 16).

The average abundances of scallops (>= 90 mm) in simulated surveys in the *Fmult*=0.3 run are similar to actual dredge survey estimates for all sub-populations (Table 17). The inter-annual variation in survey abundances are also similar between the simulated surveys and actual surveys, providing some support for the level of recruitment variation assumed for the simulations.

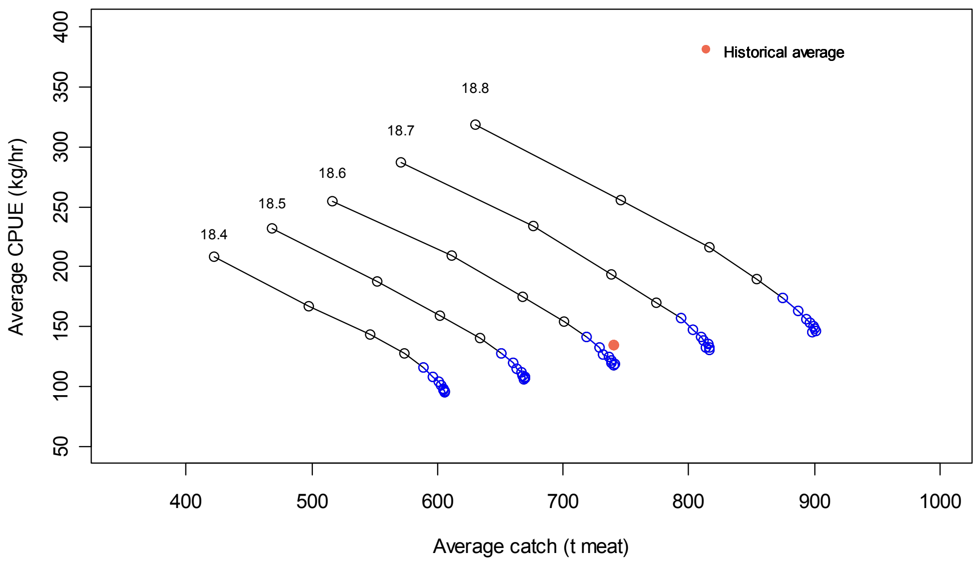

Figure 6: Estimates of average CPUE (kg/hr) versus average catch (t meatweight) at alternative values of $\ln\left(R_0\right)$ (ranging from 18.4 to 18.8) and exploitation rates (ranging from 0.08 to 0.40). The blue points indicate exploitation rates from 0.2 to 0.41.

Table 15: Estimated scallop catch and scallop biomass (for scallops >= 95 mm) from dredge surveys (taken from Williams 2009 - table 1 for estimated catch, table 6 for survey biomass). % harvest is the annual ratio of catch to survey biomass calculated by summing the highlighted values. * indicates years when not all scallop beds were surveyed.

	Estimated catch (t green)				Survey scallops biomass (>= 95 mm)				
Year	Hauraki	Mercury Islands	Little Barrier	Bay of Plenty	Hauraki	Mercury Islands	Little Barrier	Bay of Plenty	Exploitation rate
1974	0	26	0	0					
1975	0	76	0	0					
1976	0	98	0	14					
1977	0	574	0	136					
1978	164	729	3	65					
1979	282	362	51	91					
1980	249	690	23	77	–	1 197	–	–	0.58*
1981	332	743	41	72	–	1 092	–	–	0.68*
1982	687	385	49	80	–	725	–	–	0.53*
1983	687	715	120	31	–	998	–	–	0.72*
1984	524	525	62	12	800	1 092	–	–	0.55*
1985	518	277	82	0	2 000	966	–	–	0.27*
1986	135	576	305	19	1 500	1 313	–	–	0.25*
1987	676	556	136	62	–	1 628	–	–	0.34*
1988	19	911	234	3	–	–	–	–	
1989	24	253	95	1	–	–	–	–	
1990	98	691	114	0	608	767	–	–	0.57*
1991	472	822	98	0	266	824	–	–	1.19*
1992	67	686	68	76	73	1 272	–	–	0.56*
1993	11	229	60	149	41	748	–	735	0.26*
1994	17	139	48	119	3	481	–	153	0.43*
1995	25	323	176	50	26	445	258	509	0.46
1996	25	359	193	18	28	619	346	241	0.48
1997	26	473	165	15	508	623	402	269	0.38
1998	1	199	2	1	506	641	99	132	0.15
1999	0	12	17	18	18	176	19	87	0.16
2000	0	24	2	44	–	–	–	–	
2001	1	63	85	12	19	142	152	70	0.42
2002	0	79	12	112	90	255	85	70	0.41
2003	63	153	13	223	160	428	146	206	0.48
2004	27	333	27	237	471	2 546	119	340	0.18
2005	21	872	75	0	475	5 036	282	518	0.15
2006	28	846	60	0	685	4 397	321	237	0.17
2007	51	373	45	2	304	3 449	211	365	0.11
Avg. all years									0.42
Avg. 1995-2007									0.30

Table 16: Average density of legal-sized scallops (>= 90 mm) and average proportions of the total catch for sub-populations from simulations using *Survey* decision rules with alternative *Fmult* parameters and historical average densities and proportions of the total catch.

	Density of legal-sized scallops					Proportion of total catch			
Fmult	HG	MI	BP	BI		HG	MI	BP	BI
0.08	0.12	0.44	0.19	0.41		0.01	0.61	0.10	0.27
0.11	0.12	0.39	0.18	0.36		0.02	0.62	0.11	0.25
0.14	0.11	0.35	0.17	0.32		0.02	0.62	0.12	0.24
0.17	0.11	0.32	0.16	0.29		0.02	0.61	0.13	0.23
0.2	0.11	0.30	0.15	0.27		0.03	0.61	0.13	0.23
0.23	0.11	0.29	0.15	0.27		0.03	0.61	0.13	0.23
0.26	0.11	0.28	0.15	0.26		0.03	0.61	0.14	0.23
0.29	0.11	0.28	0.15	0.25		0.03	0.61	0.14	0.23
0.32	0.11	0.28	0.15	0.25		0.03	0.61	0.14	0.22
0.35	0.11	0.27	0.15	0.25		0.03	0.61	0.14	0.22
0.38	0.11	0.27	0.15	0.25		0.03	0.61	0.14	0.22
0.41	0.10	0.27	0.15	0.25		0.03	0.61	0.14	0.22
Historical averages									
1991–2008	0.11	0.43	0.14	0.34	1980–2007	0.23	0.59	0.11	0.07
1991–2000	0.05	0.22	0.08	0.13	2000–2007	0.05	0.71	0.08	0.16
2001–2008	0.17	0.58	0.18	0.50					

Table 17: The mean, standard deviation, and CV of the number of scallops >= 90 mm (millions) from surveys (unadjusted) and from operating model simulated surveys model (*Fmult*=0.3).

	Survey			Simulated		
Sub-stock	Mean	Std. dev	CV	Mean	Std. dev	CV
HG	0.90	1.18	1.30	0.92	0.98	1.07
MI	6.17	8.54	1.39	6.30	7.78	1.24
BP	1.46	1.23	0.85	2.65	2.53	0.96
BI	1.45	1.28	0.88	1.93	1.93	1.00

5.3 Baseline Trials

Simulations were run for the *LimitCPUE* and *Survey* decision rules, with the decision rule parameters given in Table 7. For each set of rule parameters a single 3000 year simulation was run and summary statistics calculated. Detailed summaries of performance statistics are tabulated in Appendix A.

50-year subsets of some example simulations are shown in Figure 7. The MI sub-population dominates the total population abundance of legal-sized scallops through most of the simulation period. The simulated survey data shows bias, in particular when abundance is low. This is of course because scallop beds below a threshold density (0.06 scallops/m^2) are not included in the simulated survey.

5.3.1 LimitCPUE decision rules

For the *LimitCPUE* rules, the mean catches increased from 61 t to 78 t meatweight over the range of *TACC* examined (Figure 8, Appendix Table A1). The inter-annual variability in catches is relatively low for the 80 t *TACC* rules, increasing with higher *TACCs*. CPUE increases with higher CPUE thresholds (*CPUElim*), although decreases as the *TACC* parameter increases (Figure 8).

The proportion of years that the *TACC* is taken decreases from 55–58% for rules with 80 t *TACC* to 30 –34% for rules with 120 t *TACC* (Figure 9). At the 80 t TACC, both closure of all fishing beds and exceeding the maximum number of hours available for fishing influenced the ability to take the entire *TACC*. With higher *TACC*s, exceeding the maximum number of hours available for fishing was a stronger factor in the ability to take the full *TACC*. Higher *CPUElim* values increases the probability that all fishing beds will be closed, but decreases the probability that the maximum number of hours available for fishing becomes limiting. The mean number of scallop beds fished each year ranges between 5 and 6 (Appendix Table A1).

With SSB aggregated across all sub-populations, the median *SSBratio* is relatively high for all *LimitCPUE* decision rules ranging from 0.37 to 0.49 across the rules (Figure 9, Appendix Table A1). The probability that SSB is below 20% of the virgin level is less than 10% for all rules with *CPUElim* parameters of 50 or higher, and decreases with higher *CPUElim*. The probability that SSB is below 10% of the virgin level is less than 0.2% for all the baseline *LimitCPUE* simulations.

The individual sub-populations show considerable variability in their median *SSBratio*s and the probability that SSB is below 20% of the virgin level (Figure 10). The two sub-populations that were simulated with higher average scallop densities (MI and BI), are fished to a greater extent and therefore have lower median SSB. The probability that the SSB is below 10% B_0 is highest for the MI sub-population, ranging from 3% to 6% across the *CPUElim* decision rules. Higher *CPUElim* values decrease the probability that sub-population abundance falls below 10% B_0, but decreasing the *TACC* level has little influence on this statistic (Appendix Table A2).

5.3.2 Survey decision rules

For the *Survey* decision rules, mean catch ranges from 72 t to 92 t, with the *BaseTACC* parameter having little influence on the distribution of catches (Figure 8, Appendix Table A1). Variability in catches is high relative to the *LimitCPUE* rules, because the surveys allow occasional large catches. CPUE decreases with higher catches (higher *Fmult* parameters) and is somewhat less variable than for the *LimitCPUE* rules. The *BaseTACC* parameter has little influence on the catch and CPUE distributions (Figure 8).

The proportion of years that the *TACC* is taken is almost 100% for decision rules with *Fmult* parameter of 0.1, but decreases substantially with higher *Fmult* (Figure 9). Under this rule beds are not closed, so reaching the maximum number of hours available for fishing is the reason for not attaining the TACC. Under the *Survey* rules the mean number of scallop beds fished is more variable than under the *LimitTACC* rules, ranging from 5.3 to 6.8 (Appendix Table A1).

The median *SSBratio*, aggregated across sub-populations, has a similar range for the *Survey* rules as for the *LimitCPUE* rules (Figure 9, Appendix Table A1), although the probabilities that SSB is below 20% of the virgin level tend to be somewhat higher. The probability that SSB is below 20% virgin increases with increasing *Fmult* and *BaseTACC* parameter values, although the influence of the *BaseTACC* parameter is less at higher *Fmult* values. Only the decision rule with *Fmult* of 0.1 and *BaseTACC* of 22 t did not exceed the 10% probability threshold for SSB falling below 20% B_0. The probability that SSB is below 10% of the virgin level ranges from 0.8% to 3.3% across the baseline *Survey* simulations.

The individual sub-populations have considerable variability in their mean *SSBratio*s and the probability that SSB is below 20% of the virgin level (Figure 11). For the more heavily fished sub-populations, MI and BI, the probability that SSB is below 20% B_0 is greater than 10% for all *Survey* decision rules. The probability that SSB is below 10% B_0 also exceeds the Harvest Strategy Guidelines 2% limit (Appendix Table A2).

Comparing the *LimitCPUE* and *Survey* decision rules, the *LimitCPUE* rules have less variability in catch for similar mean catch levels (Figure 12), although the Survey rules generally result in higher catches. Mean CPUE, which decreases with higher mean catch, is similar for *Survey* rules and *LimitCPUE* rules that generate similar mean catches. The probability that SSB is below 20% B_0 is similar between *LimitCPUE* and *Survey* rules, given similar mean catches, however the higher catches obtained from the *Survey* rules result in generally higher risk levels. Risk (probability SSB<02.B_0) can be reduced by increasing the *CPUElim* parameter of the *LimitCPUE* rules or by decreasing the *baseTACC* parameter of the *Survey* decision rules. The median *SSBratio* is higher for *Survey* rules than for *LimitCPUE* rules that generate similar mean catches.

5.4 Sensitivity Trials

Sensitivity trials were conducted by changing assumptions of the *baseline* trials, and running simulations for both the *LimitCPUE* and *Survey* decision rules. The sensitivity trials included: a lower value for the populations scaling parameter, R_0 (*low R0*); higher fishing induced incidental mortality rates (*incidental mortality*); higher catastrophic mortality rates (*catastrophic mortality*); alternative dredge efficiency parameters (*high dredge efficiency* and *low dredge efficiency*); and an alternative structure for fishing whereby beds were fished at random (*alternative fishing*). Detailed results from the sensitivity trials are presented in Appendix Tables A1 and A2.

All sensitivity trials resulted in lower mean catches, with the exception of the *high dredge efficiency* trial (Figure 13). The patterns in the variability in catches generally followed the pattern in mean catches, with the standard deviation of catch increasing or decreasing in proportion to change in the mean catch.

For the *LimitCPUE* rules, the probability that the TACC is caught is higher for the *high dredge efficiency* trial and lower for the other sensitivity trials (Figure 14). For the *Survey* rules, the *alternative fishing* sensitivity trial results in substantially lower probabilities of catching the TACC. The remaining sensitivity trials had relatively minor effects on the probability of catching the *TACC*, depending somewhat on the values of the *Survey* decision rule parameters (Figure 14).

For both *LimitCPUE* and *Survey* decision rules, the mean CPUEs are higher for the high dredge efficiency scenarios and lower for the other sensitivity scenarios (Figure 14). In particular, CPUEs are substantially lower for the *alternative fishing* scenario.

The higher *incidental mortality* scenario results in lower median SSB and higher probability that SSB is below 20% B_0 for both the *LimitCPUE* and *Survey* decision rules (Figure 15). For the *LimitCPUE* rule, the probability of SSB being below 20% B_0 is reduced substantially with higher *CPUElim* values, and there are a few rules that meet the 10% probability threshold under all sensitivity trials. For the *Survey* rule, the probability of SSB being below 20% B_0 is above 10% for all rules for at least one of the sensitivity trials.

Fishing scallop beds at random, as in the alternative fishing scenario, results in higher mean SSB and lower probability that SSB is below 20% B_0 for both the *LimitCPUE* and *Survey* decision rules (Figure 15). For all *LimitCPUE* and *Survey* decision rules the probability that SSB is below 20% B_0 is 10% or less. Under the alternative fishing scenario fishing is more evenly distributed among the sub-populations, resulting in somewhat higher average stock levels.

The effect of the *low R0* scenario differs between the *LimitCPUE* and *Survey* decision rules. For the *LimitCPUE* rules, mean SSB is generally lower than in the *baseline* simulations and the probability that SSB is below 20% B_0 is also lower. Under this family of rules, the TACCs are higher relative to the stock size but the threshold CPUEs also kick in at relatively higher stock sizes. For the *Survey* based rules, mean SSB is higher and the probability that SSB is below 20% B_0 is lower than in the *baseline* simulations. With lower overall abundance fewer beds are surveyed so ACE adjustments are lower.

6. DISCUSSION

Evaluating the alternative decision rules investigated in this MSE requires consideration of the conflicting objectives of maximizing catch (or economic value), minimizing inter-annual variability in the catch, and ensuring safety (conservation) of the resource. Additional considerations may include maintaining high catch rates and ensuring that the TACCs can regularly be caught.

The Harvest Strategy Standard (HSS) provides the necessary guidance for ensuring safety of the resource and compliance with the Fisheries Act. The HSS defines target and limit reference points for fisheries resources and management actions associated with achieving targets and avoiding limits. The Standard is consistent with the requirement of the Fisheries Act to maintain stocks at or above, or moving stocks to or above, a level that can produce maximum sustainable yield.

The HSS defines three reference points: 1) a target that is MSY-compatible or better about which the population should fluctuate with 50% probability of being above or below the target; 2) a soft limit, set at 20% B_0 for stocks with targets below 40%B_0; and a hard limit, set at 10%B_0 for stocks with targets below 40%B_0 (Anon. 2008). Where MSE is conducted for a fishery resource, the HSS defines minimum performance criteria for acceptable harvest strategies. These are: a 50% probability or higher of achieving the stock target; a 10% probability or lower of breaching the soft limit; and a 2% probability or lower of breaching the hard limit. The Standard allows the possibility of combining the last two requirements into the single maximum probability of 5% of exceeding the soft limit.

To evaluate the alternative decision rules investigated in this MSE against the HSS, we consider the performance of the entire Coromandel population rather than the performance of each sub-population. Although simulated as distinct production units, there is certainly some exchange of spat among areas, and the Coromandel area is managed under a single TACC.

For the purpose of this MSE, the appropriate target reference point for the Coromandel scallop resource is B_{msy} as it is clearly defined within the operating model. Under constant fishing mortality rate simulations, B_{msy} was estimated to be 33% of B_0. All decision rules examined under the *baseline* simulations attain the HSS requirement of a 50% probability or higher of maintaining the stock above B_{msy}. Additionally, all *LimitCPUE* decision rules and *Survey* rules with a low *Fmult* value meet the requirement of a 2% probability or lower of stock biomass falling below 10%B_0 for the *baseline* trials.

Of the three HSS criteria, the 10% probability of stock biomass being below 20% B_0 is the most stringent. For the *baseline* simulations, all *LimitCPUE* rules with a CPUE threshold (*CPUElim*) above 40 kg/hr meet the 20%B_0 criterion but only the *Survey* rule with survey biomass multiplier (*Fmult*) of 0.1 and *BaseTACC* of 22 t meets the criterion.

Of the sensitivity trials, the higher *incidental mortality* trials and the *high dredge efficiency* trials have the greatest effect on increasing the probability that stock biomass falls below 20% B_0. All *LimitCPUE* decision rules with *CPUElim* of 70 kg/hr attain the 10% limit for this risk criterion, while none of the *Survey* rules attain the risk criterion across the range of sensitivity trials. Unlike the *Survey* rules, the *LimitCPUE* rules close scallop beds at low abundance which provides some buffer as stock abundance decreases. Results from the sensitivity trials suggest at least some of the *LimitCPUE* rules could be considered for managing the Coromandel fishery.

The two types of decision rules examined, the *LimitCPUE* and the *Survey*-based rules, behave quite differently with the *LimitCPUE* rules approximating constant catch rules and the *Survey* rules approximating constant harvest rate rules. As such the *Survey* rules have higher catch variability at the same mean catch level of *LimitCPUE* rules. However the rule types are not strict constant catch and constant harvest rate rules, and as such their behaviour differs somewhat from those forms of harvest strategy. For example, Cryer et al. (2003) found that constant harvest rate rules produced higher mean catches with lower risk than constant catch rules. Results from this MSE suggest that similar mean catches can be attained at similar risk levels for the *LimitCPUE* and *Survey* rules. The *LimitCPUE* rules are not strictly constant catch rules as scallop beds are closed when catch rates fall below defined thresholds, thus they function somewhere between constant catch and constant escapement type rules.

The Coromandel scallop fishery has been managed with a constant F type strategy, with catch limits determined by applying estimated $F_{0.1}$ values to survey-based pre-fishery biomass estimates. The $F_{0.1}$ values have been calculated (yield-per-recruit type analysis) based on two scenarios, one that includes incidental adult mortality effects and another that additionally includes incidental juvenile mortality effects. Under the first scenario, $F_{0.1}$ was calculated as 0.431 with egg production at 0.456 of the unfished level (Cryer & Parkinson 2006). Under the second scenario, $F_{0.1}$ was calculated as 0.274 with egg production at 0.446 of the unfished level. The stochastic constant-F simulations conducted here suggest that F values of 0.25 to 0.45 result in median reductions in egg production (actually, gonad mass in this analysis) of 0.22 to 0.38 of the unfished level with probabilities of stock biomass being below 20%B_0 of 0.15 to 0.45. It is likely that our results differ from those of Cryer & Parkinson (2006) because we consider stochastic recruitment and possibly also because we assume slower growth and consequently higher incidental mortality effects.

The *LimitCPUE* decision rules assume that accurate catch rate data can be collected and monitored to ensure that fishing beds are closed in a timely manner. The Coromandel scallop industry implemented a logbook system in 2009 and demonstrated their ability to maintain such a system and generate weekly bed-specific catch rate data that could be used to manage the fishery. Vessel effects are likely to affect catch rates and standardization may be required to use the CPUE data within a fisheries management context.

Cryer (2001) used Coromandel scallop fishery CPUE data in a depletion analysis and found that the data did not provide reliable estimates of biomass. Whether this was a function of precision and accuracy of the data or inconsistencies between the assumptions of the analysis and the actual dynamics of the stock and fisheries was not clear. The 2009 Coromandel scallop logbook data showed declines in catch rates through the season, but this was not consistent among all fished beds. Comparison of scallop density estimates implied by the commercial fishery catch rates and pre-season survey density estimates showed reasonable agreement, suggesting that the fishery CPUE is a reasonable proxy for scallop abundance.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Anon. (2008). Harvest Strategy Standard for New Zealand fisheries. New Zealand Ministry of Fisheries. 25 p.

Bian, R; Williams, J.R.; Smith M. (2010). Modelling dredge efficiency for the Coromandel and Northland scallop fisheries. Working document for Ministry of Fisheries Shellfish Fishery Assessment

Working Group SFWG 10/07. 49p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Breen, P.A.; Haist, V.; Smith, A.N.H.; Starr, P.J. (2008). Review of the NSS decision rule for stocks CRA7 and CRA8 and development of new operational management procedures. *New Zealand Fisheries Assessment Report* 2008/55. 71 p.

Bull, M.F. (1988). New Zealand Scallop. *New Zealand Fisheries Assessment Research Document* 88/25. 17 p. (Unpublished document held by NIWA library, Wellington.)

Cryer, M. (2001). An appraisal of an in-season depletion method of estimating biomass and yield in the Coromandel. *New Zealand Fisheries Assessment Report* 2001/8. 28 p.

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

Cryer, M.; Morrison M. (1997). Incidental effects of commercial scallop fisheries. Final Report for Ministry of Fisheries Project AKSC03. 65p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Cryer, M.; Parkinson, D.M. (2006). Biomass surveys and stock assessments for the Coromandel and Northland scallop fishery, 2005. *New Zealand Fisheries Assessment Report* 2006/34. 53 p.

Haist, V.; Francis, R.I.C.C.; Stokes, K. (2006). Management strategy evaluation for New Zealand hoki fisheries: results of initial analyses. *New Zealand Fisheries Assessment Report* 2006/31. 45 p.

Holdsworth, J.C.; Walshe, K. (2009). Harvest survey from the recreational scallop and rock lobster fisheries in eastern Coromandel, 2007–08. Working document for Marine Amateur Fisheries Working Group MAFWG 09/02. 25 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

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

Williams, J.R. (2009). Biomass surveys and stock assessments for the Coromandel scallop fishery, 2008. *New Zealand Fisheries Assessment Report* 2009/02. 31 p.

Williams, J.R.; Babcock, R.C. (2005). Assessment of size at maturity and gonad index methods for the scallop *Pecten novaezelandiae. New Zealand Journal of Marine and Freshwater Research 2005/39*: 851–864.

Williams, J.R.; Tuck, I.D.; Parkinson, D.M. (2007). Biomass survey and stock assessment for the Coromandel and Northland scallop fishery, 2006. *New Zealand Fisheries Assessment Report* 2007/24. 41 p.

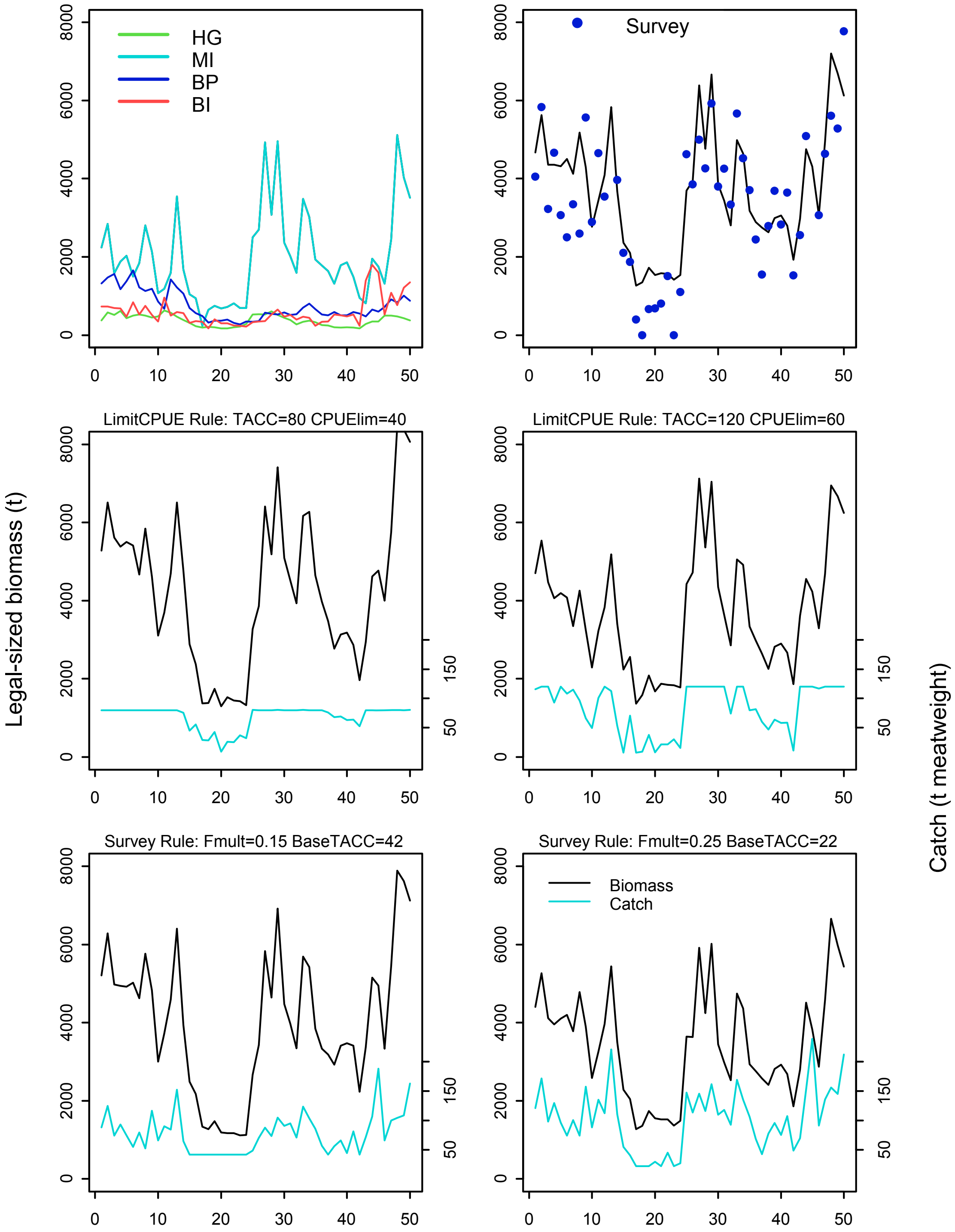

Figure 7: Simulated time-series (50 years) of stock biomass (legal sized scallops) by sub-population (upper left), and total population with survey biomass estimates (upper right), illustrated for the survey based rule with *Fmult* = 0.20 and *baseTACC* = 22; (lower panels) stock biomass and catch for four different decision rules.

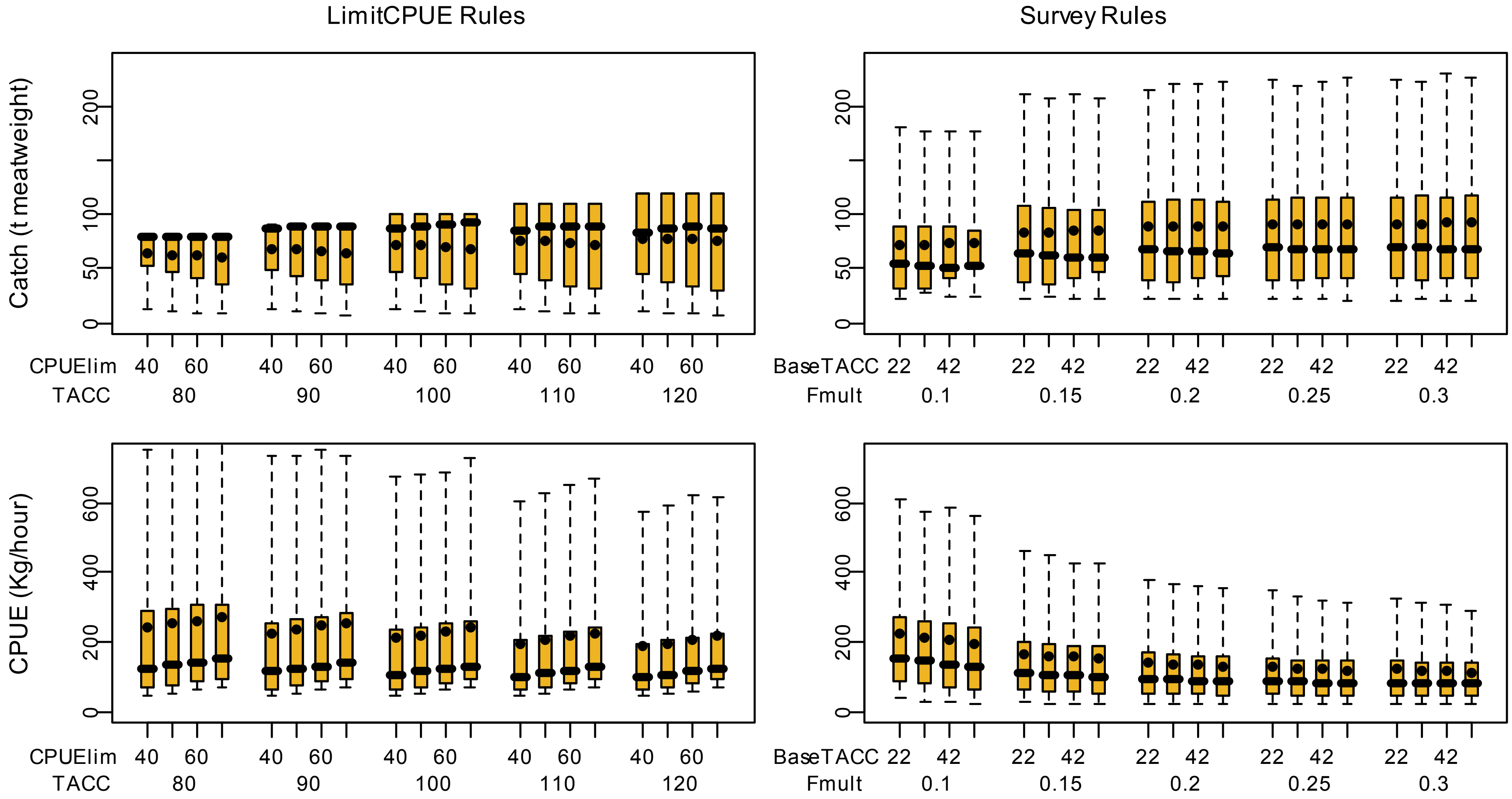

Figure 8: Distribution of catch (tonnes greenweight, upper panels) and CPUE (kg/hr, lower panels) for the *LimitCPUE* and *Survey* decision rules with alternative parameter values. Shaded boxes show the interquartile range and whiskers show the 5th and 95th percentiles of the distributions. Means are indicated with points and medians with horizontal bars.

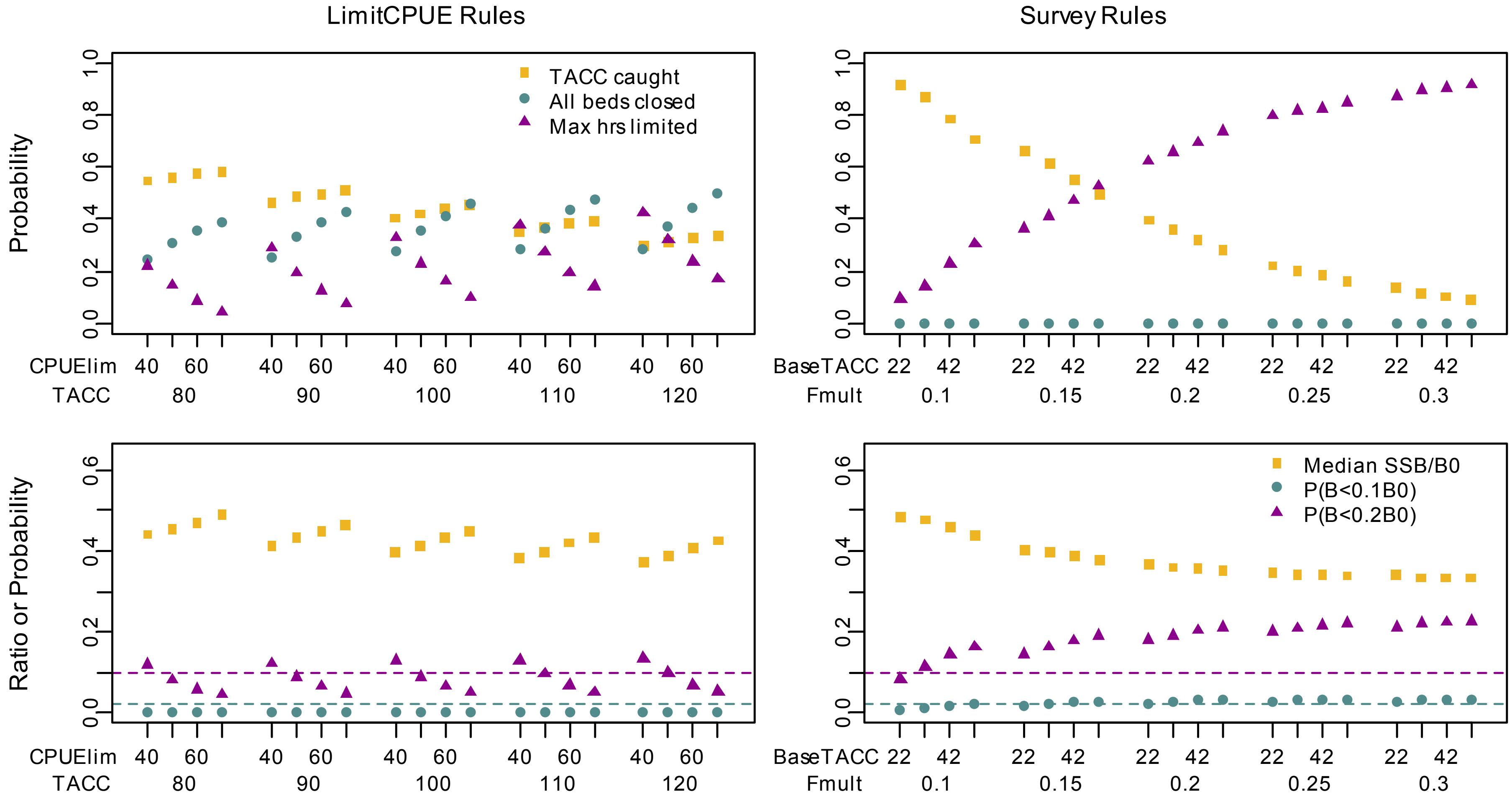

Figure 9: Upper Panels: probability that the TACC is caught, probability that all scallop beds are closed, and probability that the maximum number of fishing hours is used. Lower Panels: mean ratio of spawning stock biomass (SSB) to virgin SSB and probabilities that SSB is less than 20% B_0 and less than 10% B_0. Figures on the left are for simulation runs based on *LimitCPUE* decision rules and figures on the right are for simulation runs based on *Survey* decision rules. Statistics related to SSB are based on the aggregate SSB across all sub-populations.

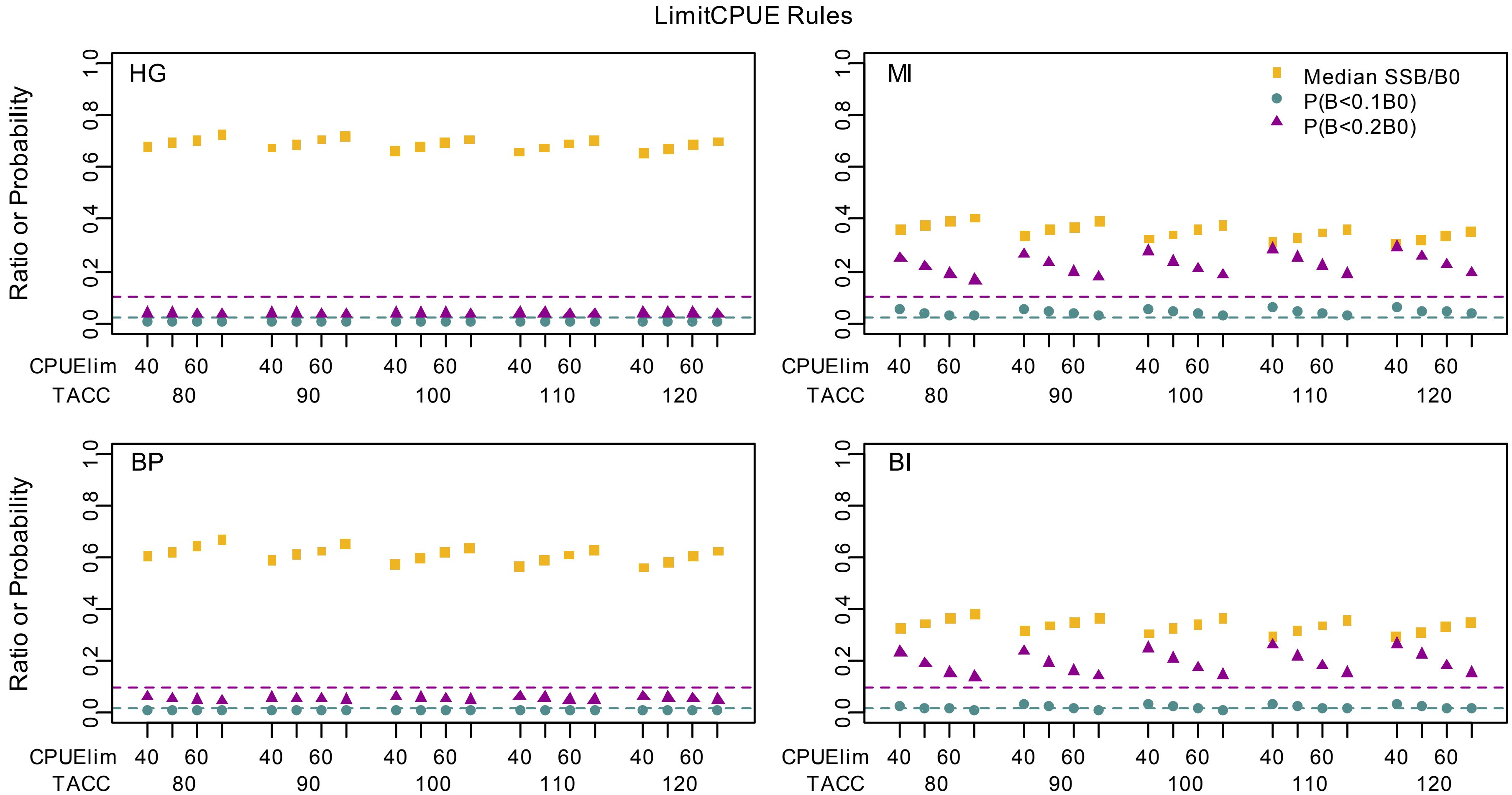

Figure 10: Mean ratio of spawning stock biomass to virgin spawning stock biomass (B_0) and probabilities that spawning stock biomass is less than 20% B_0 and less than 10% B_0, for the four Coromandel sub-populations (HG – Hauraki Gulf, MI – Mercury Islands, BP – Bay of Plenty, BI – Barrier Islands), for simulation runs based on *LimitCPUE* decision rules.

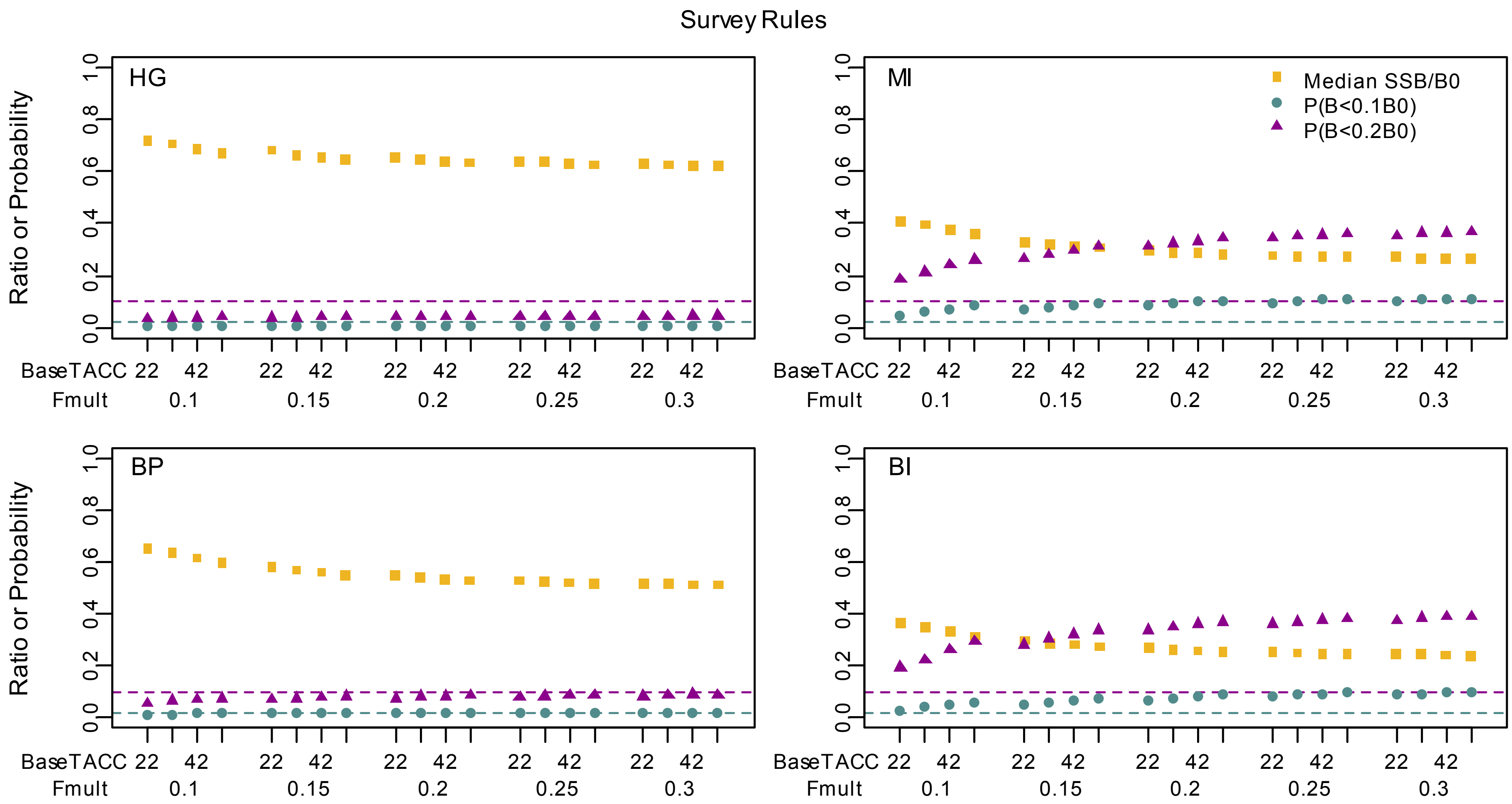

Figure 11: Mean ratio of spawning stock biomass to virgin spawning stock biomass (B_0) and probabilities that spawning stock biomass is less than 20% B_0 and less than 10% B_0, for the four Coromandel sub-populations (HG – Hauraki Gulf, MI – Mercury Islands, BP – Bay of Plenty, BI – Barrier Islands), for simulation runs based on *Survey* decision rules.

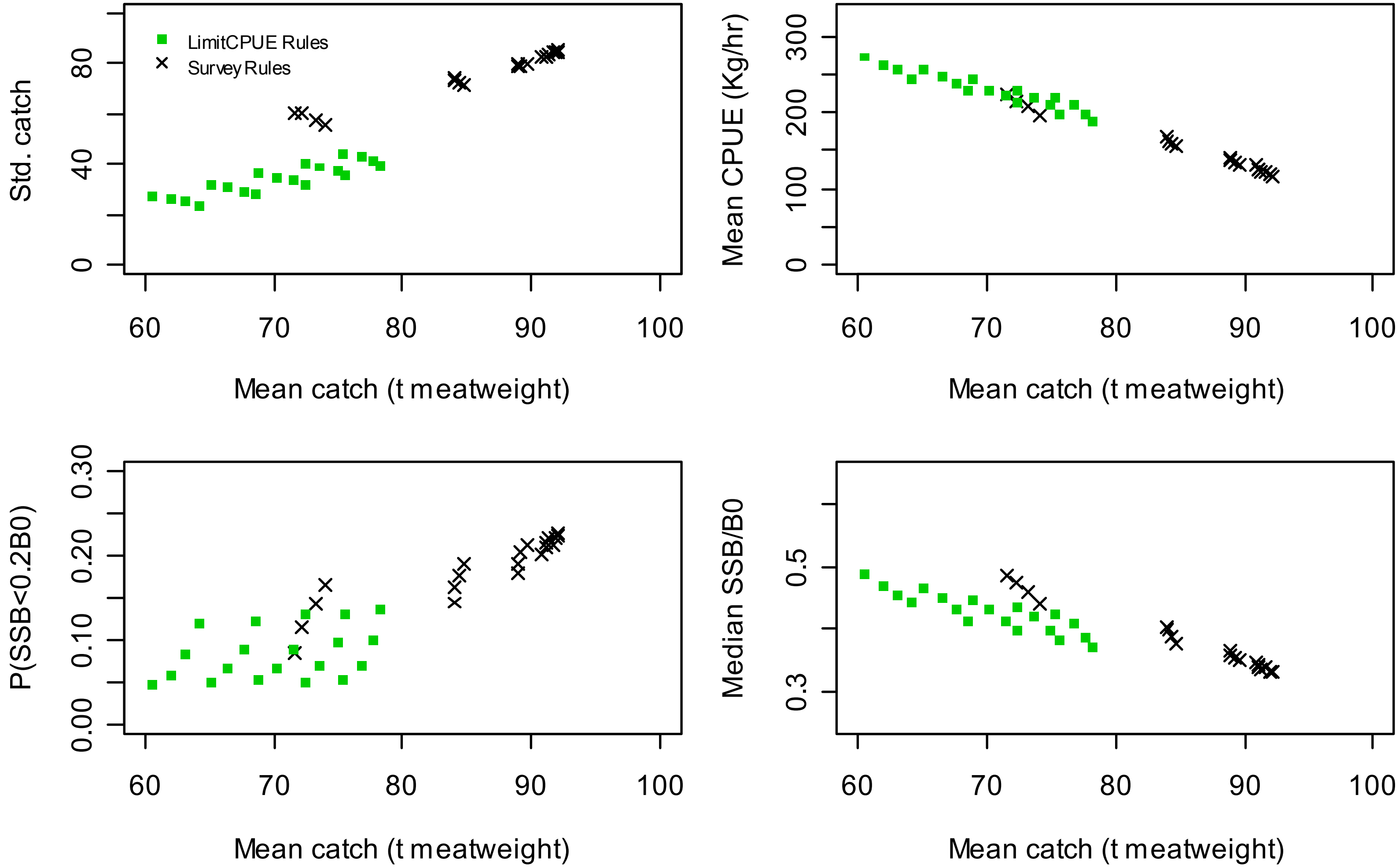

Figure 12: Comparison of summary statistics from the *LimitCPUE* and *Survey* decision rules for Coromandel simulations.

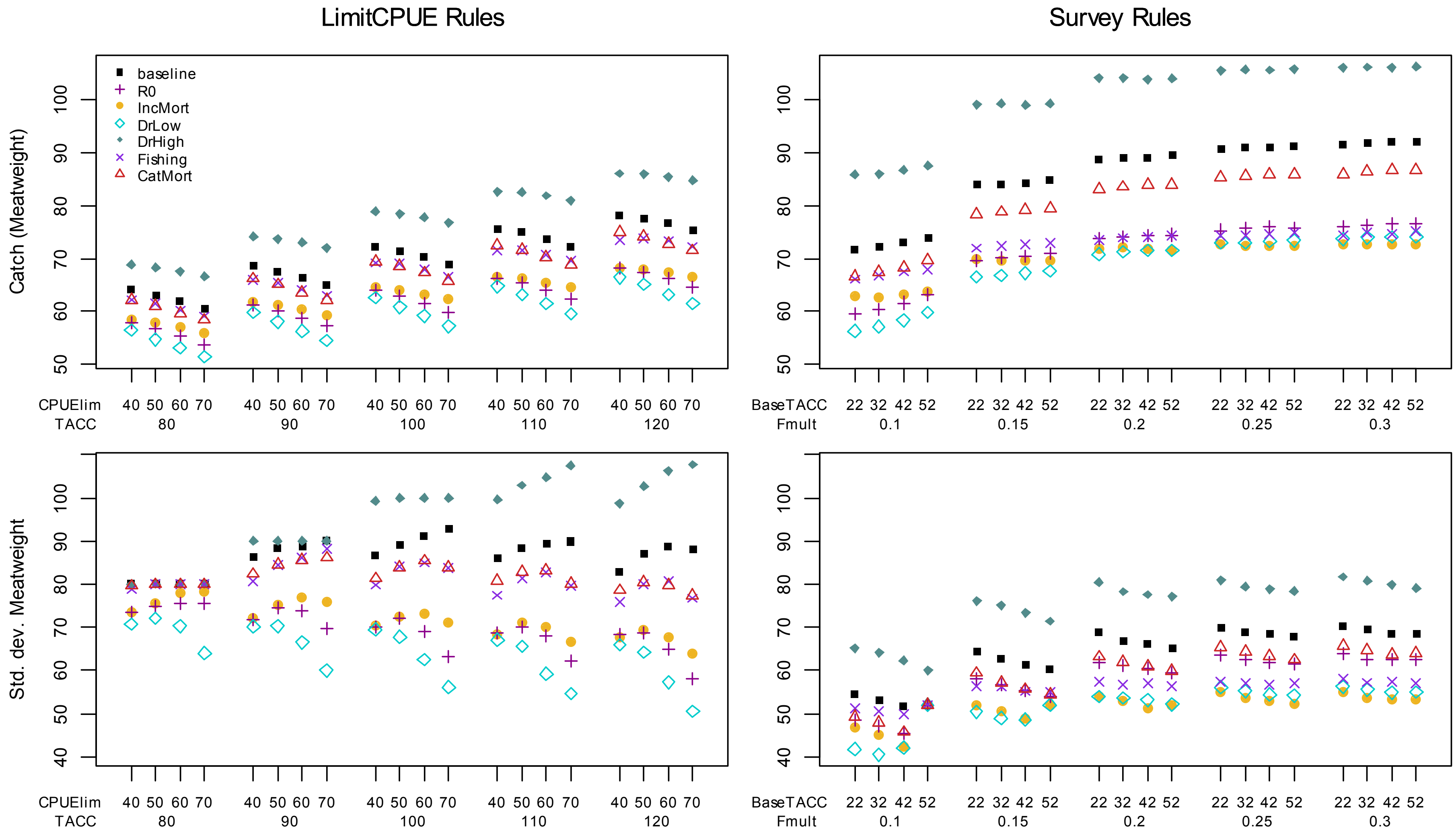

Figure 13: Mean catch (t meatweight) and the standard deviation of catch (t meatweight) for baseline and sensitivity trials simulated under the *LimitCPUE* and *Survey* decision rules.

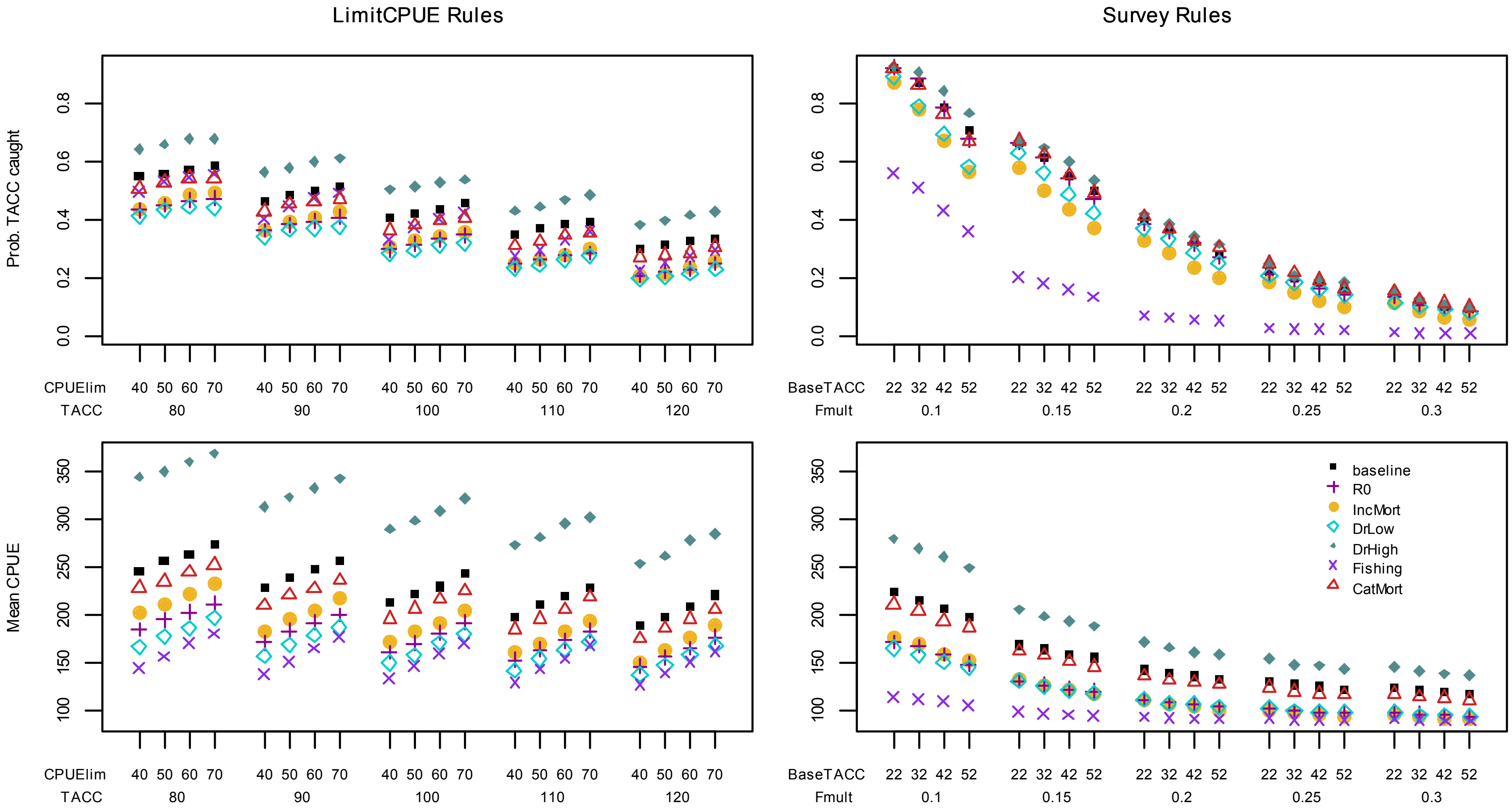

Figure 14: The probability that the TACC is caught and the mean CPUE (kg/hr) for baseline and sensitivity trials simulated under the *LimitCPUE* and *Survey* decision rules.

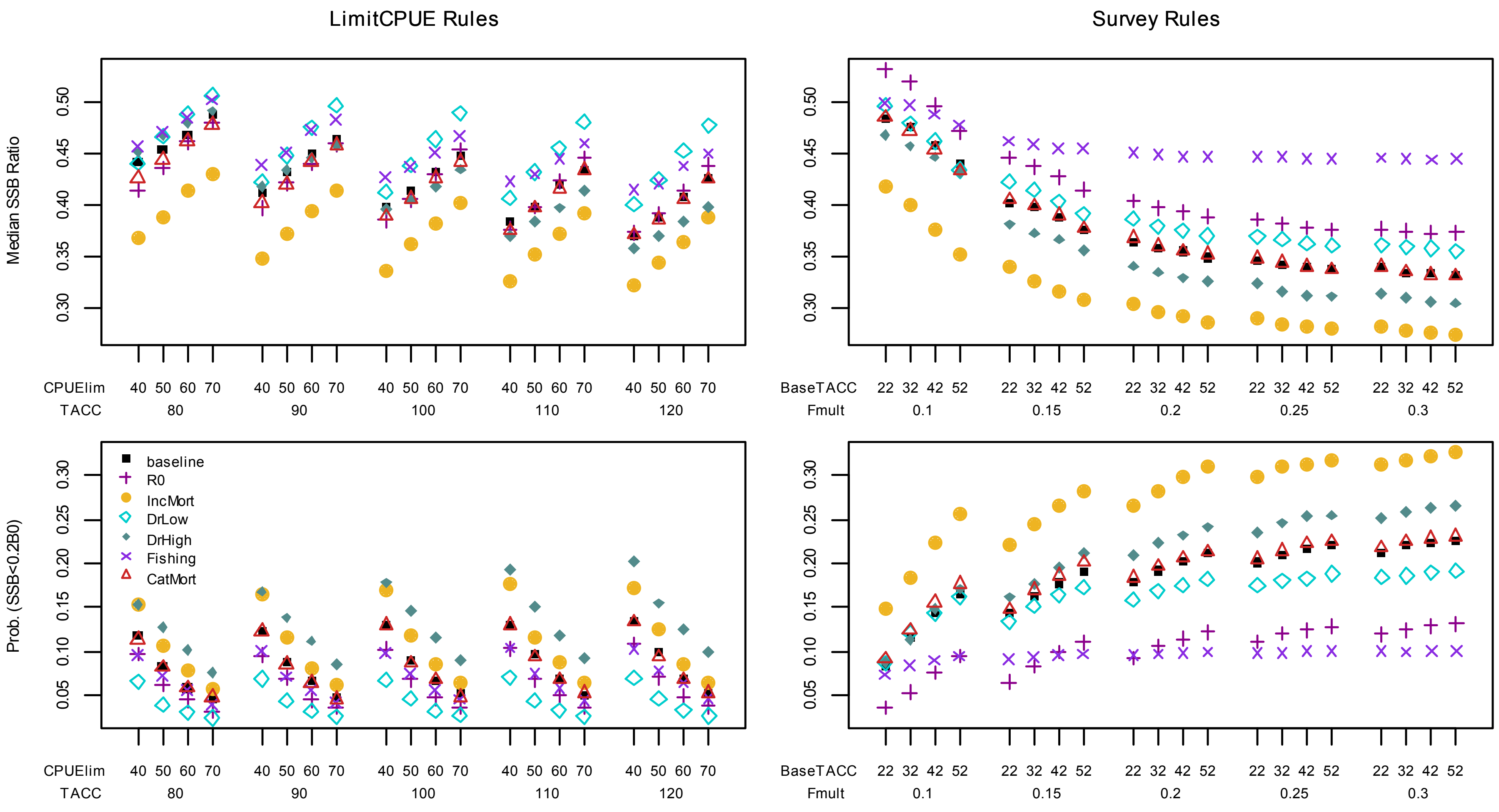

Figure 15: The median SSB ratio and the probability that SSB is less than 20%B_0 for baseline and sensitivity trials simulated under the *LimitCPUE* and *Survey* decision rules.

Appendix Table A1: Summary statistics for the Coromandel scallop baseline simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	64.2	80.0	23.6	521.9	0.55	245	129	0.44	0.00	0.12	5.5
50	80	63.2	80.0	25.1	514.4	0.56	256	135	0.45	0.00	0.08	5.3
60	80	62.1	80.0	26.3	504.9	0.57	263	144	0.47	0.00	0.06	5.0
70	80	60.6	80.0	27.4	493.2	0.58	273	153	0.49	0.00	0.05	4.8
40	90	68.6	86.4	27.7	557.5	0.46	228	118	0.41	0.00	0.12	5.7
50	90	67.6	88.3	29.4	549.9	0.49	239	126	0.43	0.00	0.09	5.4
60	90	66.5	88.9	30.5	541.3	0.50	248	134	0.45	0.00	0.07	5.2
70	90	65.1	90.0	31.8	529.5	0.51	257	143	0.46	0.00	0.05	4.9
40	100	72.4	86.8	31.8	587.3	0.40	212	109	0.40	0.00	0.13	5.8
50	100	71.5	89.0	33.5	581.1	0.42	222	119	0.41	0.00	0.09	5.6
60	100	70.3	91.1	34.9	570.9	0.44	229	125	0.43	0.00	0.07	5.3
70	100	68.9	92.9	36.1	559.5	0.45	243	135	0.45	0.00	0.05	5.1
40	110	75.6	86.1	35.7	612.3	0.35	198	105	0.38	0.00	0.13	5.9
50	110	75.0	88.5	37.3	608.3	0.37	210	112	0.40	0.00	0.10	5.7
60	110	73.6	89.5	38.9	597.3	0.39	219	122	0.42	0.00	0.07	5.4
70	110	72.4	89.9	40.1	588.0	0.39	229	130	0.43	0.00	0.05	5.2
40	120	78.3	82.9	39.2	633.3	0.30	189	100	0.37	0.00	0.14	6.0
50	120	77.7	87.0	41.0	629.2	0.31	197	110	0.39	0.00	0.10	5.8
60	120	76.8	88.7	42.7	622.2	0.33	209	117	0.41	0.00	0.07	5.5
70	120	75.3	88.0	44.1	611.0	0.34	220	127	0.43	0.00	0.05	5.2
BaseTACC	Fmult											
22	0.1	71.6	54.4	60.6	583.7	0.92	224	152	0.48	0.01	0.08	5.3
32	0.1	72.2	53.0	60.6	587.6	0.87	215	150	0.48	0.01	0.12	5.5
42	0.1	73.2	51.6	57.8	595.1	0.79	207	141	0.46	0.02	0.14	5.7
52	0.1	74.1	52.1	56.0	601.0	0.71	198	130	0.44	0.02	0.16	5.9
22	0.15	84.0	64.4	74.1	682.1	0.66	168	113	0.40	0.02	0.14	6.2
32	0.15	84.1	62.6	73.5	681.7	0.61	164	111	0.40	0.02	0.16	6.2
42	0.15	84.4	61.3	72.8	684.5	0.55	159	107	0.39	0.03	0.18	6.3
52	0.15	84.7	60.2	71.5	685.6	0.50	155	104	0.38	0.03	0.19	6.4
22	0.2	88.9	68.7	79.6	718.7	0.40	142	97	0.36	0.02	0.18	6.5
32	0.2	89.0	66.9	79.1	718.5	0.36	138	95	0.36	0.03	0.19	6.6
42	0.2	89.2	66.0	79.2	719.9	0.32	135	93	0.36	0.03	0.20	6.7
52	0.2	89.6	65.1	80.3	722.9	0.28	132	91	0.35	0.03	0.21	6.7
22	0.25	90.8	69.8	82.7	731.7	0.22	130	90	0.35	0.03	0.20	6.6
32	0.25	91.1	68.8	83.2	733.5	0.20	127	88	0.34	0.03	0.21	6.7
42	0.25	91.1	68.5	82.4	733.7	0.19	124	87	0.34	0.03	0.22	6.7
52	0.25	91.3	67.9	83.4	735.2	0.16	122	86	0.34	0.03	0.22	6.8
22	0.3	91.7	70.3	84.3	737.2	0.14	123	86	0.34	0.03	0.21	6.7
32	0.3	91.9	69.4	84.2	739.0	0.11	120	84	0.33	0.03	0.22	6.7
42	0.3	92.1	68.6	84.4	739.6	0.10	118	84	0.33	0.03	0.22	6.8
52	0.3	92.1	68.5	85.8	740.4	0.09	116	82	0.33	0.03	0.23	6.7

Appendix Table A1: Summary statistics for the Coromandel scallop R_0 simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	58.0	73.4	26.5	470.9	0.43	184	97	0.41	0.00	0.10	5.6
50	80	56.7	74.8	27.8	460.5	0.45	195	105	0.44	0.00	0.06	5.3
60	80	55.3	75.5	29.0	449.9	0.47	203	114	0.46	0.00	0.04	5.0
70	80	53.8	75.4	29.9	437.3	0.47	212	122	0.48	0.00	0.03	4.7
40	90	61.3	71.7	30.4	497.5	0.36	171	90	0.40	0.00	0.10	5.7
50	90	60.2	74.4	32.0	488.6	0.38	183	101	0.42	0.00	0.07	5.4
60	90	58.8	73.8	33.1	477.5	0.39	192	110	0.44	0.00	0.04	5.1
70	90	57.2	69.7	34.1	464.7	0.41	200	119	0.46	0.00	0.04	4.8
40	100	64.0	70.1	34.1	518.4	0.29	161	86	0.39	0.00	0.10	5.8
50	100	63.0	72.2	35.9	510.6	0.31	170	97	0.41	0.00	0.07	5.5
60	100	61.4	69.0	37.1	498.3	0.33	181	107	0.43	0.00	0.05	5.2
70	100	59.9	63.2	37.8	486.0	0.35	192	116	0.45	0.00	0.04	4.9
40	110	66.3	68.7	37.2	536.7	0.25	152	85	0.38	0.00	0.10	5.9
50	110	65.4	70.2	39.1	529.4	0.26	163	94	0.40	0.00	0.07	5.6
60	110	64.1	68.1	40.5	519.3	0.28	173	104	0.42	0.00	0.05	5.3
70	110	62.3	62.3	41.5	505.3	0.28	183	114	0.44	0.00	0.04	5.0
40	120	68.2	68.2	40.2	551.1	0.21	146	84	0.37	0.00	0.11	6.0
50	120	67.5	68.8	42.1	545.6	0.22	156	91	0.39	0.00	0.07	5.6
60	120	66.2	64.9	43.6	535.6	0.23	165	101	0.41	0.00	0.05	5.4
70	120	64.5	58.1	44.7	522.7	0.25	176	112	0.44	0.00	0.04	5.1
BaseTACC	Fmult											
22	0.1	59.5	48.4	40.4	484.0	0.92	172	132	0.53	0.00	0.04	5.6
32	0.1	60.3	47.0	39.1	489.2	0.88	167	129	0.52	0.00	0.05	5.8
42	0.1	61.7	45.3	37.4	499.7	0.78	158	120	0.50	0.00	0.08	5.9
52	0.1	63.1	52.0	35.4	511.0	0.68	148	108	0.47	0.00	0.09	6.2
22	0.15	69.7	57.9	47.9	564.8	0.67	130	100	0.45	0.00	0.07	6.4
32	0.15	70.3	56.5	48.7	568.5	0.62	126	97	0.44	0.00	0.08	6.5
42	0.15	70.5	55.4	47.4	569.5	0.54	122	94	0.43	0.01	0.10	6.6
52	0.15	71.0	53.9	46.1	573.4	0.47	119	89	0.41	0.01	0.11	6.6
22	0.2	73.9	62.0	51.4	596.4	0.39	111	86	0.40	0.00	0.09	6.7
32	0.2	74.2	61.0	51.9	598.2	0.36	108	85	0.40	0.00	0.11	6.8
42	0.2	74.3	60.5	51.5	598.6	0.32	106	83	0.39	0.01	0.11	6.8
52	0.2	74.5	59.4	51.9	599.0	0.27	104	81	0.39	0.01	0.12	6.9
22	0.25	75.3	63.4	52.2	606.0	0.21	102	80	0.39	0.00	0.11	6.9
32	0.25	75.7	62.5	53.2	608.6	0.19	99	78	0.38	0.01	0.12	6.9
42	0.25	75.9	61.7	54.0	609.6	0.17	98	78	0.38	0.01	0.12	6.9
52	0.25	75.9	61.6	54.0	609.0	0.14	97	77	0.38	0.01	0.13	6.9
22	0.3	75.9	63.8	53.4	609.7	0.13	97	77	0.38	0.01	0.12	7.0
32	0.3	76.4	62.5	54.4	613.2	0.10	95	76	0.37	0.01	0.12	7.0
42	0.3	76.5	62.4	55.1	613.5	0.09	94	76	0.37	0.01	0.13	6.9
52	0.3	76.5	62.6	54.2	613.4	0.08	93	75	0.37	0.01	0.13	6.9

Appendix Table A1: Summary statistics for the Coromandel scallop Incidental Mortality simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	58.5	73.3	26.2	475.0	0.44	201	97	0.37	0.00	0.15	5.7
50	80	57.8	75.6	27.2	470.1	0.45	210	107	0.39	0.00	0.11	5.5
60	80	57.0	77.9	28.3	463.3	0.48	222	118	0.41	0.00	0.08	5.1
70	80	56.0	78.3	29.0	454.9	0.49	233	126	0.43	0.00	0.06	4.9
40	90	61.8	72.1	30.0	501.1	0.36	181	92	0.35	0.00	0.16	5.9
50	90	61.2	75.1	31.5	496.9	0.39	195	101	0.37	0.00	0.12	5.6
60	90	60.3	77.0	32.5	489.8	0.41	204	110	0.39	0.00	0.08	5.3
70	90	59.3	76.0	33.3	481.3	0.42	217	121	0.41	0.00	0.06	5.0
40	100	64.5	70.5	33.7	521.9	0.31	172	87	0.34	0.00	0.17	6.0
50	100	64.1	72.4	35.2	519.2	0.33	182	96	0.36	0.00	0.12	5.7
60	100	63.2	73.2	36.3	512.9	0.34	192	107	0.38	0.00	0.09	5.4
70	100	62.2	71.2	37.2	505.2	0.36	205	116	0.40	0.00	0.06	5.1
40	110	66.5	68.4	37.0	537.8	0.25	159	84	0.33	0.00	0.18	6.1
50	110	66.2	70.9	38.5	535.9	0.27	169	94	0.35	0.00	0.12	5.8
60	110	65.5	70.0	39.8	530.9	0.28	182	104	0.37	0.00	0.09	5.5
70	110	64.5	66.6	40.9	523.2	0.30	193	114	0.39	0.00	0.07	5.2
40	120	68.2	67.7	40.0	550.8	0.20	150	82	0.32	0.00	0.17	6.1
50	120	68.0	69.5	41.6	549.6	0.21	162	91	0.34	0.00	0.12	5.9
60	120	67.5	67.8	43.1	546.4	0.24	175	102	0.36	0.00	0.09	5.6
70	120	66.6	63.9	44.1	539.8	0.25	188	112	0.39	0.00	0.06	5.3
BaseTACC	Fmult											
22	0.1	62.8	46.8	55.1	511.8	0.87	177	121	0.42	0.03	0.15	5.7
32	0.1	62.8	45.1	52.3	510.3	0.78	168	114	0.40	0.04	0.18	6.0
42	0.1	63.2	42.3	50.5	513.3	0.67	159	101	0.38	0.05	0.22	6.2
52	0.1	63.8	52.0	49.3	516.8	0.57	151	92	0.35	0.05	0.26	6.4
22	0.15	70.0	51.9	63.3	568.0	0.58	133	87	0.34	0.04	0.22	6.5
32	0.15	69.6	50.7	63.0	563.6	0.50	125	84	0.33	0.05	0.25	6.6
42	0.15	69.7	48.8	63.1	563.5	0.44	121	79	0.32	0.06	0.27	6.7
52	0.15	69.6	52.0	62.1	562.6	0.37	116	75	0.31	0.06	0.28	6.8
22	0.2	71.9	53.8	66.6	581.1	0.33	110	74	0.30	0.05	0.27	6.8
32	0.2	72.1	53.1	67.8	581.4	0.28	106	72	0.30	0.06	0.28	6.9
42	0.2	71.8	51.1	66.8	578.9	0.24	103	70	0.29	0.06	0.30	6.9
52	0.2	71.7	52.1	66.6	577.4	0.19	100	68	0.29	0.07	0.31	6.9
22	0.25	72.6	54.9	68.8	584.8	0.18	100	68	0.29	0.06	0.30	6.9
32	0.25	72.5	53.8	70.1	583.0	0.15	97	67	0.28	0.06	0.31	7.0
42	0.25	72.3	53.0	68.9	581.5	0.12	95	66	0.28	0.07	0.31	7.0
52	0.25	72.4	52.2	68.5	582.2	0.10	93	65	0.28	0.07	0.32	7.0
22	0.3	72.7	54.8	69.0	584.3	0.11	95	66	0.28	0.06	0.31	7.0
32	0.3	72.8	53.5	70.3	584.9	0.08	92	65	0.28	0.06	0.32	7.0
42	0.3	72.7	53.4	70.6	583.8	0.06	90	64	0.28	0.07	0.32	7.0
52	0.3	72.6	53.3	69.4	583.2	0.05	89	63	0.27	0.07	0.33	7.0

Appendix Table A1: Summary statistics for the Coromandel scallop Dredge Efficiency Low simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	56.5	70.7	27.1	458.6	0.41	166	93	0.44	0.00	0.07	5.4
50	80	54.7	72.1	28.7	444.3	0.43	177	103	0.47	0.00	0.04	5.1
60	80	53.1	70.3	29.7	431.0	0.44	186	112	0.49	0.00	0.03	4.8
70	80	51.5	64.0	30.4	418.0	0.44	197	122	0.51	0.00	0.02	4.5
40	90	59.8	70.2	30.9	485.1	0.34	157	89	0.42	0.00	0.07	5.6
50	90	58.1	70.3	32.7	471.6	0.36	169	100	0.45	0.00	0.04	5.2
60	90	56.3	66.5	33.7	456.8	0.37	178	109	0.47	0.00	0.03	4.9
70	90	54.5	60.0	34.5	442.4	0.38	187	119	0.50	0.00	0.03	4.6
40	100	62.6	69.5	34.5	506.3	0.28	150	86	0.41	0.00	0.07	5.7
50	100	60.9	67.8	36.2	493.8	0.29	158	95	0.44	0.00	0.05	5.4
60	100	59.2	62.5	37.3	480.0	0.31	171	106	0.46	0.00	0.03	5.0
70	100	57.2	56.2	38.1	464.2	0.32	179	115	0.49	0.00	0.03	4.7
40	110	64.7	67.1	37.5	523.4	0.23	141	84	0.41	0.00	0.07	5.7
50	110	63.2	65.6	39.2	511.9	0.24	154	95	0.43	0.00	0.04	5.5
60	110	61.5	59.2	40.7	498.2	0.26	163	105	0.46	0.00	0.03	5.1
70	110	59.6	54.7	41.5	482.9	0.27	172	115	0.48	0.00	0.03	4.8
40	120	66.5	66.0	40.5	536.7	0.19	137	83	0.40	0.00	0.07	5.8
50	120	65.2	64.2	42.3	526.9	0.20	147	93	0.42	0.00	0.05	5.5
60	120	63.2	57.3	43.6	511.7	0.21	157	103	0.45	0.00	0.03	5.2
70	120	61.5	50.6	44.8	498.0	0.23	168	114	0.48	0.00	0.03	4.8
BaseTACC	Fmult											
22	0.1	56.3	41.8	47.0	458.3	0.89	165	114	0.50	0.01	0.09	5.4
32	0.1	57.2	40.5	45.4	464.5	0.79	157	111	0.48	0.01	0.12	5.7
42	0.1	58.3	42.1	43.2	472.8	0.69	150	100	0.46	0.02	0.14	5.9
52	0.1	59.9	52.0	42.3	485.3	0.58	144	91	0.43	0.02	0.16	6.0
22	0.15	66.5	50.4	57.8	539.7	0.63	130	88	0.42	0.01	0.13	6.1
32	0.15	66.8	48.9	57.1	540.9	0.56	125	85	0.41	0.02	0.15	6.2
42	0.15	67.3	48.6	57.4	544.7	0.49	120	83	0.40	0.02	0.16	6.3
52	0.15	67.7	52.0	55.6	546.7	0.42	117	77	0.39	0.02	0.17	6.3
22	0.2	70.8	53.9	62.9	572.1	0.37	111	76	0.39	0.02	0.16	6.4
32	0.2	71.3	53.6	63.5	575.4	0.33	107	75	0.38	0.02	0.17	6.5
42	0.2	71.6	53.2	62.7	577.9	0.28	106	73	0.38	0.02	0.17	6.5
52	0.2	71.6	52.1	62.5	576.9	0.25	103	71	0.37	0.02	0.18	6.5
22	0.25	73.1	56.1	66.7	588.3	0.21	101	71	0.37	0.02	0.17	6.6
32	0.25	72.9	55.2	64.5	587.0	0.18	99	70	0.37	0.02	0.18	6.6
42	0.25	73.3	54.4	65.8	590.3	0.16	98	69	0.36	0.02	0.18	6.6
52	0.25	73.4	54.2	66.0	590.1	0.14	97	68	0.36	0.02	0.19	6.6
22	0.3	73.8	56.3	67.5	593.3	0.11	97	69	0.36	0.02	0.18	6.5
32	0.3	74.0	55.6	67.5	594.4	0.10	95	68	0.36	0.02	0.19	6.6
42	0.3	74.1	54.9	67.5	595.5	0.09	94	68	0.36	0.02	0.19	6.6
52	0.3	74.2	55.0	66.8	595.7	0.08	93	66	0.36	0.02	0.19	6.6

Appendix Table A1: Summary statistics for the Coromandel scallop Dredge Efficiency High simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	68.9	80.0	20.4	561.4	0.64	345	182	0.45	0.00	0.15	5.4
50	80	68.3	80.0	21.7	556.6	0.66	351	189	0.47	0.00	0.13	5.3
60	80	67.6	80.0	22.7	551.0	0.68	361	192	0.48	0.00	0.10	5.1
70	80	66.6	80.0	23.8	543.0	0.68	369	198	0.49	0.00	0.08	4.9
40	90	74.2	90.0	24.7	603.8	0.56	314	156	0.42	0.00	0.17	5.7
50	90	73.7	90.0	26.0	600.3	0.58	323	165	0.43	0.00	0.14	5.5
60	90	73.0	90.0	27.1	594.9	0.60	333	172	0.45	0.00	0.11	5.3
70	90	72.1	90.0	28.3	586.9	0.61	343	183	0.46	0.00	0.09	5.1
40	100	78.9	99.2	29.0	641.0	0.50	290	141	0.40	0.01	0.18	5.8
50	100	78.5	99.9	30.2	637.9	0.51	299	149	0.40	0.00	0.15	5.7
60	100	77.8	100.0	31.6	632.5	0.53	309	154	0.42	0.00	0.12	5.4
70	100	76.8	100.0	32.6	624.4	0.54	322	168	0.43	0.00	0.09	5.3
40	110	82.6	99.6	33.0	670.3	0.43	273	128	0.37	0.01	0.19	6.0
50	110	82.5	103.0	34.5	670.0	0.44	281	136	0.38	0.00	0.15	5.8
60	110	81.9	104.8	35.9	665.4	0.47	296	144	0.40	0.00	0.12	5.6
70	110	81.0	107.4	37.2	657.9	0.48	302	156	0.41	0.00	0.09	5.4
40	120	86.1	98.7	37.0	698.1	0.38	254	120	0.36	0.01	0.20	6.1
50	120	86.0	102.7	38.5	697.7	0.40	262	127	0.37	0.00	0.15	5.9
60	120	85.4	106.2	40.1	693.5	0.42	278	137	0.38	0.00	0.12	5.7
70	120	84.8	107.8	41.1	688.9	0.43	286	146	0.40	0.00	0.10	5.5
BaseTACC	Fmult											
22	0.1	86.0	65.2	74.1	701.2	0.93	280	189	0.47	0.01	0.09	5.4
32	0.1	86.0	64.2	72.3	700.7	0.91	270	182	0.46	0.02	0.11	5.5
42	0.1	86.8	62.3	71.9	705.6	0.84	261	178	0.45	0.02	0.15	5.7
52	0.1	87.6	60.1	70.5	711.4	0.77	249	168	0.43	0.03	0.17	5.9
22	0.15	99.1	76.1	89.5	805.2	0.67	206	137	0.38	0.02	0.16	6.2
32	0.15	99.3	75.1	88.0	806.1	0.65	198	132	0.37	0.03	0.18	6.4
42	0.15	99.1	73.4	87.0	803.8	0.60	193	130	0.37	0.03	0.20	6.4
52	0.15	99.4	71.4	85.6	805.4	0.54	188	125	0.36	0.04	0.21	6.5
22	0.2	104.2	80.4	96.8	842.1	0.42	171	115	0.34	0.03	0.21	6.6
32	0.2	104.2	78.3	95.9	842.3	0.38	166	110	0.33	0.03	0.22	6.7
42	0.2	103.9	77.6	92.7	839.9	0.34	161	109	0.33	0.04	0.23	6.7
52	0.2	104.1	77.2	93.6	839.7	0.32	158	108	0.33	0.04	0.24	6.8
22	0.25	105.6	80.9	98.4	851.2	0.25	153	105	0.32	0.03	0.23	6.8
32	0.25	105.8	79.4	99.4	852.2	0.20	148	103	0.32	0.04	0.25	6.9
42	0.25	105.7	78.9	97.5	851.4	0.19	146	102	0.31	0.04	0.25	6.9
52	0.25	105.9	78.3	97.6	851.9	0.18	144	101	0.31	0.04	0.25	6.9
22	0.3	106.2	81.7	98.3	854.8	0.15	145	101	0.31	0.04	0.25	6.8
32	0.3	106.3	80.8	99.2	854.3	0.13	141	98	0.31	0.04	0.26	6.9
42	0.3	106.2	79.9	98.1	854.2	0.10	138	98	0.31	0.04	0.26	6.9
52	0.3	106.4	79.0	98.5	855.2	0.10	136	97	0.31	0.05	0.27	6.9

Appendix Table A1: Summary statistics for the Coromandel scallop Alternative Fishing simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	62.2	78.8	24.2	505.6	0.49	143	106	0.46	0.00	0.10	7.1
50	80	61.5	80.0	25.8	499.9	0.53	156	118	0.47	0.00	0.07	6.7
60	80	60.3	80.0	26.8	491.0	0.55	170	129	0.48	0.00	0.06	6.3
70	80	59.1	80.0	27.7	481.1	0.56	180	140	0.50	0.00	0.04	6.0
40	90	66.0	80.6	28.3	535.5	0.40	138	101	0.44	0.00	0.10	7.2
50	90	65.5	84.5	29.9	531.6	0.44	151	113	0.45	0.00	0.07	6.8
60	90	64.2	86.1	31.0	522.2	0.47	165	124	0.47	0.00	0.06	6.4
70	90	63.1	88.2	32.2	512.9	0.49	177	134	0.48	0.00	0.04	6.0
40	100	69.2	79.8	32.2	560.4	0.33	134	97	0.43	0.00	0.10	7.2
50	100	69.0	84.0	33.8	559.2	0.37	147	108	0.44	0.00	0.07	6.8
60	100	67.9	85.0	35.2	551.3	0.40	159	119	0.45	0.00	0.06	6.4
70	100	66.6	83.6	36.2	541.1	0.42	171	131	0.47	0.00	0.05	6.1
40	110	71.5	77.4	35.7	578.0	0.27	130	93	0.42	0.00	0.10	7.2
50	110	71.6	81.5	37.4	579.5	0.30	143	106	0.43	0.00	0.08	6.8
60	110	70.8	82.8	39.1	574.2	0.33	154	117	0.45	0.00	0.06	6.4
70	110	69.6	79.7	40.2	564.9	0.36	167	127	0.46	0.00	0.04	6.0
40	120	73.5	76.0	38.5	593.1	0.22	126	92	0.41	0.00	0.10	7.3
50	120	73.9	80.0	40.7	597.1	0.25	139	104	0.42	0.00	0.08	6.8
60	120	73.4	80.7	42.5	593.8	0.27	150	114	0.44	0.00	0.06	6.4
70	120	72.3	76.7	43.7	585.3	0.30	162	125	0.45	0.00	0.05	6.0
BaseTACC	Fmult											
22	0.1	66.2	51.2	53.6	536.2	0.56	114	87	0.50	0.00	0.07	9.1
32	0.1	66.9	50.6	53.9	541.1	0.51	111	84	0.50	0.00	0.08	9.2
42	0.1	67.5	49.9	53.3	545.4	0.43	109	80	0.49	0.00	0.09	9.2
52	0.1	68.0	52.0	52.9	548.9	0.36	105	77	0.48	0.00	0.09	9.3
22	0.15	72.0	56.4	59.0	580.3	0.20	98	73	0.46	0.00	0.09	9.5
32	0.15	72.5	56.2	60.2	583.7	0.18	96	72	0.46	0.00	0.09	9.5
42	0.15	72.6	55.2	60.4	584.1	0.16	95	71	0.46	0.00	0.10	9.5
52	0.15	73.0	55.0	60.8	587.2	0.13	94	71	0.45	0.00	0.10	9.5
22	0.2	73.6	57.5	61.6	591.3	0.07	93	69	0.45	0.00	0.10	9.5
32	0.2	74.0	56.8	62.3	594.3	0.06	91	68	0.45	0.00	0.10	9.6
42	0.2	74.2	56.9	62.7	595.4	0.06	91	68	0.45	0.00	0.10	9.6
52	0.2	74.3	56.5	62.6	596.2	0.05	90	68	0.45	0.00	0.10	9.6
22	0.25	74.3	57.4	63.8	596.4	0.03	91	68	0.45	0.00	0.10	9.6
32	0.25	74.4	57.1	63.2	597.4	0.02	90	67	0.45	0.00	0.10	9.6
42	0.25	74.7	56.7	64.4	599.1	0.02	89	67	0.45	0.00	0.10	9.6
52	0.25	74.9	57.0	63.7	600.5	0.02	89	67	0.44	0.00	0.10	9.6
22	0.3	74.3	58.0	63.2	596.2	0.01	91	68	0.45	0.00	0.10	9.6
32	0.3	74.9	57.2	64.5	600.0	0.01	89	67	0.44	0.00	0.10	9.6
42	0.3	74.7	57.3	64.2	599.1	0.01	88	67	0.44	0.00	0.10	9.6
52	0.3	75.1	57.0	65.2	601.8	0.01	88	66	0.44	0.00	0.10	9.6

Appendix Table A1: Summary statistics for the Coromandel scallop Catastrophic Mortality simulations. Statistics are for the aggregate over the sub-populations.

Rule parameters		Meatweight			Gweight	Prob. TACC	CPUE		SSB	Prob. SSB<		Mean beds
CPUElim	TACC	Mean	Med.	Std.Dev.	Mean	caught	Mean	Med.	Med	0.1 B_0	0.2B_0	fished
40	80	62.1	79.7	24.9	504.9	0.51	229	116	0.43	0.00	0.11	5.4
50	80	61.0	80.0	26.5	496.0	0.53	235	126	0.44	0.00	0.08	5.2
60	80	59.8	80.0	27.6	485.7	0.54	245	132	0.46	0.00	0.06	4.9
70	80	58.4	80.0	28.4	474.9	0.54	253	140	0.48	0.00	0.05	4.7
40	90	66.3	82.3	28.8	537.4	0.43	210	107	0.40	0.00	0.12	5.6
50	90	65.1	84.6	30.5	528.9	0.45	221	115	0.42	0.00	0.08	5.3
60	90	63.7	85.6	31.8	517.2	0.46	228	125	0.44	0.00	0.06	5.1
70	90	62.2	86.2	32.9	505.6	0.47	236	133	0.46	0.00	0.05	4.8
40	100	69.5	81.4	32.8	563.4	0.36	196	101	0.39	0.00	0.13	5.7
50	100	68.5	84.0	34.5	556.2	0.38	207	110	0.41	0.00	0.09	5.4
60	100	67.3	85.4	35.9	546.6	0.39	216	118	0.43	0.00	0.07	5.2
70	100	65.8	83.8	36.9	534.1	0.41	225	128	0.44	0.00	0.05	5.0
40	110	72.5	80.7	36.5	586.4	0.31	185	98	0.38	0.00	0.13	5.8
50	110	71.8	82.9	38.2	581.4	0.32	195	105	0.40	0.00	0.09	5.5
60	110	70.3	83.1	39.7	570.7	0.34	205	115	0.42	0.00	0.07	5.3
70	110	68.8	80.1	40.8	558.3	0.35	218	124	0.43	0.00	0.05	5.1
40	120	75.0	78.6	39.8	606.0	0.27	175	95	0.37	0.00	0.13	5.9
50	120	74.3	80.5	41.7	600.8	0.28	186	104	0.39	0.00	0.09	5.6
60	120	72.9	79.8	43.1	590.5	0.29	195	112	0.40	0.00	0.07	5.4
70	120	71.6	77.4	44.5	580.3	0.31	206	122	0.42	0.00	0.05	5.1
BaseTACC	Fmult											
22	0.1	66.6	49.2	57.5	542.9	0.92	211	145	0.48	0.01	0.09	5.3
32	0.1	67.5	47.9	56.1	548.5	0.86	204	140	0.47	0.02	0.12	5.5
42	0.1	68.4	45.7	53.8	555.8	0.76	194	132	0.45	0.02	0.16	5.7
52	0.1	69.7	52.1	51.7	566.3	0.67	187	119	0.43	0.03	0.18	5.9
22	0.15	78.4	59.4	68.4	636.2	0.67	161	108	0.41	0.02	0.15	6.0
32	0.15	78.8	57.1	70.0	639.0	0.62	158	106	0.40	0.03	0.17	6.1
42	0.15	79.2	55.7	68.2	641.0	0.55	151	103	0.39	0.03	0.19	6.3
52	0.15	79.6	54.5	68.7	643.2	0.49	146	98	0.38	0.03	0.20	6.3
22	0.2	83.2	63.2	75.1	672.6	0.41	135	92	0.37	0.03	0.18	6.4
32	0.2	83.6	62.1	75.1	675.5	0.37	131	90	0.36	0.03	0.20	6.5
42	0.2	83.9	60.9	73.9	677.2	0.32	129	90	0.36	0.04	0.21	6.5
52	0.2	84.1	59.9	74.5	677.5	0.30	126	87	0.35	0.04	0.21	6.6
22	0.25	85.3	65.5	77.8	687.9	0.25	123	85	0.35	0.03	0.20	6.6
32	0.25	85.6	64.4	77.5	689.4	0.22	119	84	0.34	0.03	0.21	6.6
42	0.25	85.9	63.3	78.3	691.4	0.19	117	83	0.34	0.04	0.22	6.7
52	0.25	86.0	62.5	78.7	691.9	0.16	115	81	0.34	0.04	0.23	6.6
22	0.3	86.0	65.7	77.8	692.2	0.15	117	82	0.34	0.03	0.22	6.5
32	0.3	86.6	64.8	79.2	696.4	0.12	113	80	0.34	0.04	0.23	6.6
42	0.3	86.9	63.6	80.2	698.5	0.11	112	80	0.33	0.04	0.23	6.6
52	0.3	86.8	64.0	80.1	697.7	0.10	111	79	0.33	0.04	0.23	6.7

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the baseline simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – median SSB relative to B_0; $0.1B_0$ and $0.2B_0$ – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den
40	80	0.92	0.00	0.01	0.11	0.51	0.01	0.25	0.27	0.78	0.00	0.03	0.13	0.41	0.01	0.25	0.20
50	80	0.93	0.00	0.01	0.11	0.53	0.01	0.22	0.27	0.80	0.00	0.02	0.13	0.43	0.00	0.20	0.21
60	80	0.93	0.00	0.01	0.11	0.54	0.00	0.18	0.28	0.81	0.00	0.02	0.13	0.44	0.00	0.14	0.22
70	80	0.94	0.00	0.01	0.11	0.56	0.00	0.13	0.29	0.83	0.00	0.02	0.14	0.46	0.00	0.08	0.22
40	90	0.90	0.00	0.01	0.11	0.47	0.01	0.28	0.25	0.75	0.00	0.03	0.13	0.38	0.01	0.27	0.19
50	90	0.91	0.00	0.01	0.11	0.48	0.01	0.25	0.25	0.77	0.00	0.03	0.13	0.40	0.00	0.24	0.20
60	90	0.92	0.00	0.01	0.11	0.50	0.01	0.21	0.26	0.78	0.00	0.02	0.13	0.41	0.00	0.17	0.20
70	90	0.93	0.00	0.01	0.11	0.52	0.00	0.15	0.27	0.80	0.00	0.02	0.13	0.43	0.00	0.10	0.21
40	100	0.89	0.00	0.01	0.11	0.44	0.01	0.30	0.23	0.72	0.00	0.03	0.12	0.36	0.01	0.29	0.18
50	100	0.90	0.00	0.01	0.11	0.45	0.01	0.27	0.24	0.74	0.00	0.03	0.12	0.37	0.01	0.25	0.18
60	100	0.91	0.00	0.01	0.11	0.46	0.01	0.22	0.25	0.76	0.00	0.03	0.13	0.39	0.00	0.18	0.19
70	100	0.92	0.00	0.01	0.11	0.48	0.01	0.16	0.25	0.77	0.00	0.02	0.13	0.40	0.00	0.10	0.20
40	110	0.88	0.00	0.01	0.11	0.41	0.01	0.32	0.22	0.70	0.00	0.03	0.12	0.34	0.01	0.31	0.17
50	110	0.89	0.00	0.01	0.11	0.42	0.01	0.29	0.23	0.71	0.00	0.03	0.12	0.35	0.01	0.27	0.18
60	110	0.90	0.00	0.01	0.11	0.43	0.01	0.24	0.23	0.73	0.00	0.02	0.12	0.37	0.01	0.20	0.18
70	110	0.91	0.00	0.01	0.11	0.45	0.00	0.17	0.24	0.75	0.00	0.02	0.13	0.38	0.00	0.11	0.19
40	120	0.87	0.00	0.01	0.11	0.39	0.02	0.33	0.21	0.68	0.00	0.03	0.12	0.32	0.01	0.32	0.16
50	120	0.88	0.00	0.01	0.11	0.40	0.01	0.30	0.22	0.70	0.00	0.03	0.12	0.34	0.01	0.28	0.17
60	120	0.89	0.00	0.01	0.11	0.41	0.01	0.25	0.22	0.71	0.00	0.03	0.12	0.35	0.00	0.20	0.18
70	120	0.90	0.00	0.01	0.11	0.43	0.01	0.18	0.23	0.73	0.00	0.02	0.12	0.37	0.00	0.12	0.19
Bt	Fmul																
22	0.1	0.96	0.00	0.00	0.09	0.57	0.00	0.07	0.24	0.87	0.00	0.02	0.12	0.49	0.01	0.07	0.20
32	0.1	0.95	0.00	0.01	0.09	0.55	0.02	0.11	0.24	0.85	0.00	0.02	0.12	0.47	0.01	0.10	0.19
42	0.1	0.93	0.00	0.01	0.09	0.52	0.03	0.16	0.23	0.82	0.00	0.03	0.11	0.44	0.02	0.16	0.18
52	0.1	0.92	0.00	0.01	0.09	0.49	0.04	0.22	0.21	0.79	0.00	0.03	0.11	0.41	0.03	0.22	0.17
22	0.15	0.92	0.00	0.01	0.09	0.45	0.01	0.13	0.20	0.77	0.00	0.02	0.11	0.39	0.01	0.13	0.16
32	0.15	0.91	0.00	0.01	0.09	0.44	0.02	0.17	0.20	0.76	0.00	0.03	0.10	0.38	0.02	0.17	0.16
42	0.15	0.90	0.00	0.01	0.09	0.42	0.04	0.22	0.19	0.74	0.00	0.03	0.10	0.36	0.03	0.22	0.15
52	0.15	0.89	0.00	0.01	0.09	0.40	0.04	0.26	0.18	0.72	0.00	0.03	0.10	0.35	0.03	0.27	0.14
22	0.2	0.89	0.00	0.01	0.09	0.38	0.02	0.20	0.17	0.71	0.00	0.03	0.10	0.34	0.01	0.21	0.14
32	0.2	0.88	0.00	0.01	0.09	0.37	0.03	0.23	0.17	0.70	0.00	0.03	0.10	0.33	0.03	0.24	0.14
42	0.2	0.87	0.00	0.01	0.09	0.36	0.04	0.26	0.16	0.68	0.00	0.03	0.10	0.32	0.03	0.28	0.13
52	0.2	0.87	0.00	0.01	0.09	0.35	0.05	0.30	0.16	0.67	0.00	0.03	0.09	0.31	0.04	0.31	0.13
22	0.25	0.87	0.00	0.01	0.09	0.34	0.02	0.26	0.16	0.67	0.00	0.03	0.09	0.31	0.02	0.25	0.13
32	0.25	0.86	0.00	0.01	0.09	0.33	0.04	0.28	0.15	0.66	0.00	0.03	0.09	0.30	0.03	0.29	0.12
42	0.25	0.86	0.00	0.01	0.09	0.32	0.05	0.30	0.15	0.65	0.00	0.03	0.09	0.29	0.04	0.32	0.12
52	0.25	0.85	0.00	0.01	0.09	0.32	0.05	0.33	0.15	0.64	0.00	0.04	0.09	0.29	0.04	0.34	0.12
22	0.3	0.86	0.00	0.01	0.09	0.32	0.03	0.29	0.15	0.65	0.00	0.03	0.09	0.29	0.02	0.29	0.12
32	0.3	0.85	0.00	0.01	0.09	0.31	0.05	0.31	0.15	0.64	0.00	0.03	0.09	0.28	0.03	0.32	0.12
42	0.3	0.85	0.00	0.01	0.09	0.30	0.05	0.33	0.14	0.63	0.00	0.04	0.09	0.28	0.04	0.34	0.12
52	0.3	0.84	0.00	0.01	0.09	0.30	0.06	0.35	0.14	0.62	0.00	0.04	0.09	0.27	0.04	0.36	0.11

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the R_0 simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – mean SSB relative to B_0; $0.1B_0$ and $0.2B_0$ – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den
40	80	0.68	0.00	0.04	0.09	0.34	0.04	0.24	0.33	0.59	0.01	0.06	0.14	0.32	0.02	0.22	0.29
50	80	0.70	0.00	0.03	0.10	0.36	0.04	0.21	0.34	0.62	0.01	0.05	0.15	0.35	0.02	0.17	0.31
60	80	0.71	0.00	0.03	0.10	0.38	0.03	0.17	0.35	0.65	0.01	0.05	0.15	0.37	0.01	0.14	0.32
70	80	0.73	0.00	0.03	0.10	0.40	0.03	0.15	0.36	0.67	0.01	0.05	0.15	0.39	0.01	0.12	0.33
40	90	0.67	0.00	0.03	0.09	0.33	0.05	0.25	0.31	0.59	0.01	0.06	0.14	0.31	0.03	0.22	0.28
50	90	0.70	0.00	0.04	0.09	0.35	0.04	0.21	0.32	0.61	0.01	0.05	0.14	0.34	0.02	0.18	0.30
60	90	0.71	0.00	0.03	0.10	0.36	0.03	0.18	0.33	0.64	0.01	0.05	0.15	0.36	0.01	0.15	0.31
70	90	0.73	0.00	0.03	0.10	0.39	0.03	0.16	0.34	0.66	0.01	0.05	0.15	0.38	0.01	0.13	0.32
40	100	0.67	0.00	0.04	0.09	0.32	0.05	0.27	0.30	0.57	0.01	0.06	0.14	0.31	0.03	0.22	0.27
50	100	0.68	0.00	0.04	0.09	0.34	0.04	0.22	0.31	0.61	0.01	0.05	0.14	0.33	0.02	0.19	0.29
60	100	0.70	0.00	0.03	0.10	0.36	0.03	0.19	0.32	0.63	0.01	0.05	0.14	0.35	0.01	0.15	0.30
70	100	0.72	0.00	0.03	0.10	0.38	0.03	0.16	0.33	0.66	0.01	0.05	0.15	0.38	0.01	0.13	0.32
40	110	0.67	0.00	0.04	0.09	0.31	0.05	0.27	0.29	0.57	0.01	0.06	0.13	0.31	0.03	0.23	0.27
50	110	0.69	0.00	0.04	0.09	0.33	0.04	0.23	0.30	0.60	0.01	0.06	0.14	0.33	0.02	0.18	0.28
60	110	0.70	0.00	0.03	0.09	0.35	0.04	0.19	0.31	0.62	0.01	0.05	0.14	0.35	0.02	0.15	0.30
70	110	0.71	0.00	0.03	0.10	0.37	0.03	0.17	0.32	0.65	0.01	0.05	0.15	0.37	0.01	0.13	0.31
40	120	0.66	0.00	0.04	0.09	0.30	0.05	0.27	0.28	0.57	0.01	0.06	0.13	0.30	0.03	0.23	0.26
50	120	0.68	0.00	0.04	0.09	0.32	0.04	0.23	0.29	0.59	0.01	0.05	0.14	0.32	0.02	0.19	0.28
60	120	0.70	0.00	0.04	0.09	0.34	0.04	0.20	0.30	0.62	0.01	0.05	0.14	0.35	0.02	0.16	0.29
70	120	0.71	0.00	0.03	0.10	0.36	0.03	0.17	0.31	0.65	0.01	0.05	0.14	0.37	0.01	0.13	0.30
Bt	Fmul																
22	0.1	0.81	0.00	0.01	0.10	0.45	0.02	0.12	0.33	0.74	0.00	0.03	0.15	0.40	0.01	0.10	0.31
32	0.1	0.79	0.00	0.01	0.10	0.44	0.03	0.14	0.33	0.72	0.00	0.03	0.15	0.40	0.02	0.13	0.30
42	0.1	0.78	0.00	0.01	0.10	0.42	0.03	0.17	0.31	0.69	0.00	0.03	0.15	0.37	0.02	0.17	0.29
52	0.1	0.76	0.00	0.01	0.10	0.39	0.04	0.20	0.30	0.67	0.01	0.04	0.14	0.35	0.02	0.20	0.28
22	0.15	0.77	0.00	0.01	0.10	0.37	0.03	0.17	0.28	0.66	0.00	0.03	0.14	0.34	0.02	0.18	0.26
32	0.15	0.75	0.00	0.01	0.10	0.36	0.04	0.19	0.27	0.65	0.00	0.04	0.14	0.33	0.02	0.19	0.25
42	0.15	0.74	0.00	0.01	0.09	0.36	0.04	0.21	0.27	0.64	0.01	0.04	0.13	0.32	0.02	0.22	0.25
52	0.15	0.74	0.00	0.01	0.09	0.35	0.04	0.23	0.26	0.63	0.01	0.04	0.13	0.31	0.03	0.24	0.24
22	0.2	0.74	0.00	0.01	0.09	0.33	0.04	0.22	0.25	0.62	0.01	0.04	0.13	0.31	0.02	0.22	0.23
32	0.2	0.74	0.00	0.01	0.09	0.33	0.04	0.23	0.25	0.62	0.01	0.04	0.13	0.30	0.02	0.23	0.23
42	0.2	0.73	0.00	0.01	0.09	0.33	0.05	0.24	0.24	0.61	0.01	0.04	0.13	0.30	0.03	0.25	0.23
52	0.2	0.72	0.00	0.01	0.09	0.32	0.05	0.25	0.24	0.61	0.01	0.04	0.13	0.29	0.03	0.26	0.22
22	0.25	0.73	0.00	0.01	0.09	0.32	0.04	0.24	0.24	0.61	0.01	0.04	0.13	0.30	0.02	0.25	0.22
32	0.25	0.72	0.00	0.01	0.09	0.31	0.05	0.25	0.23	0.60	0.01	0.04	0.13	0.29	0.03	0.26	0.22
42	0.25	0.72	0.00	0.01	0.09	0.31	0.05	0.25	0.23	0.60	0.01	0.04	0.13	0.29	0.03	0.27	0.22
52	0.25	0.72	0.00	0.01	0.09	0.31	0.05	0.26	0.23	0.60	0.01	0.04	0.12	0.29	0.03	0.27	0.22
22	0.3	0.72	0.00	0.01	0.09	0.31	0.05	0.25	0.23	0.60	0.01	0.04	0.13	0.29	0.03	0.27	0.22
32	0.3	0.72	0.00	0.01	0.09	0.31	0.05	0.25	0.23	0.60	0.01	0.04	0.12	0.29	0.03	0.27	0.21
42	0.3	0.71	0.00	0.01	0.09	0.30	0.05	0.26	0.22	0.59	0.01	0.04	0.12	0.28	0.03	0.27	0.21
52	0.3	0.71	0.00	0.01	0.09	0.30	0.05	0.26	0.22	0.59	0.01	0.04	0.12	0.28	0.03	0.28	0.21

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the Incidental Mortality simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – mean SSB relative to B_0; $0.1B_0$ and $0.2B_0$ – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den
40	80	0.64	0.00	0.04	0.11	0.30	0.07	0.31	0.37	0.54	0.01	0.06	0.16	0.28	0.04	0.29	0.32
50	80	0.66	0.00	0.04	0.11	0.32	0.05	0.27	0.38	0.57	0.01	0.06	0.17	0.31	0.03	0.23	0.34
60	80	0.68	0.00	0.03	0.12	0.34	0.04	0.23	0.39	0.60	0.01	0.05	0.17	0.33	0.02	0.19	0.36
70	80	0.70	0.00	0.03	0.12	0.35	0.03	0.19	0.41	0.63	0.01	0.05	0.18	0.35	0.02	0.16	0.37
40	90	0.63	0.01	0.04	0.11	0.29	0.07	0.33	0.35	0.53	0.01	0.07	0.16	0.27	0.05	0.31	0.30
50	90	0.65	0.00	0.04	0.11	0.31	0.05	0.28	0.36	0.56	0.01	0.06	0.16	0.30	0.03	0.25	0.32
60	90	0.68	0.00	0.04	0.11	0.33	0.05	0.24	0.37	0.58	0.01	0.06	0.17	0.32	0.02	0.20	0.34
70	90	0.70	0.00	0.03	0.12	0.34	0.04	0.21	0.39	0.62	0.01	0.05	0.17	0.33	0.02	0.17	0.36
40	100	0.62	0.00	0.04	0.11	0.27	0.07	0.34	0.33	0.52	0.01	0.07	0.15	0.27	0.05	0.31	0.29
50	100	0.64	0.00	0.04	0.11	0.29	0.06	0.29	0.35	0.55	0.01	0.06	0.16	0.29	0.03	0.25	0.31
60	100	0.66	0.00	0.04	0.11	0.31	0.04	0.26	0.36	0.58	0.01	0.05	0.17	0.31	0.03	0.21	0.33
70	100	0.69	0.00	0.03	0.11	0.33	0.04	0.22	0.37	0.60	0.01	0.05	0.17	0.33	0.02	0.18	0.35
40	110	0.62	0.01	0.04	0.11	0.27	0.07	0.35	0.31	0.51	0.01	0.07	0.15	0.26	0.05	0.33	0.28
50	110	0.64	0.00	0.04	0.11	0.29	0.06	0.30	0.33	0.54	0.01	0.06	0.16	0.28	0.04	0.27	0.30
60	110	0.67	0.00	0.04	0.11	0.30	0.05	0.25	0.34	0.57	0.01	0.06	0.16	0.30	0.03	0.22	0.32
70	110	0.68	0.00	0.04	0.11	0.33	0.04	0.23	0.36	0.59	0.01	0.05	0.17	0.32	0.02	0.19	0.34
40	120	0.61	0.00	0.04	0.10	0.26	0.08	0.36	0.30	0.51	0.01	0.07	0.15	0.26	0.05	0.33	0.28
50	120	0.64	0.00	0.04	0.11	0.28	0.06	0.31	0.32	0.54	0.01	0.06	0.15	0.28	0.03	0.27	0.30
60	120	0.66	0.00	0.04	0.11	0.30	0.05	0.26	0.33	0.57	0.01	0.06	0.16	0.30	0.03	0.22	0.31
70	120	0.68	0.00	0.03	0.11	0.32	0.04	0.22	0.35	0.58	0.01	0.05	0.16	0.32	0.02	0.19	0.33
Bt	Fmul																
22	0.1	0.68	0.01	0.04	0.11	0.35	0.07	0.26	0.35	0.59	0.02	0.08	0.17	0.30	0.06	0.28	0.31
32	0.1	0.65	0.01	0.05	0.11	0.33	0.10	0.29	0.34	0.56	0.02	0.09	0.16	0.29	0.09	0.32	0.30
42	0.1	0.63	0.01	0.05	0.11	0.30	0.12	0.34	0.33	0.54	0.02	0.10	0.16	0.27	0.12	0.37	0.28
52	0.1	0.60	0.01	0.06	0.11	0.28	0.14	0.36	0.31	0.51	0.02	0.11	0.15	0.25	0.13	0.40	0.27
22	0.15	0.62	0.01	0.05	0.11	0.27	0.12	0.36	0.28	0.51	0.02	0.09	0.15	0.24	0.10	0.39	0.25
32	0.15	0.60	0.01	0.05	0.10	0.26	0.13	0.38	0.28	0.50	0.02	0.11	0.14	0.23	0.13	0.41	0.25
42	0.15	0.59	0.01	0.06	0.10	0.25	0.15	0.40	0.27	0.49	0.02	0.11	0.14	0.23	0.14	0.44	0.24
52	0.15	0.58	0.01	0.06	0.10	0.24	0.15	0.41	0.26	0.48	0.02	0.11	0.14	0.22	0.16	0.45	0.23
22	0.2	0.59	0.01	0.05	0.10	0.24	0.14	0.41	0.25	0.47	0.02	0.10	0.14	0.22	0.14	0.45	0.22
32	0.2	0.58	0.01	0.06	0.10	0.23	0.15	0.42	0.25	0.47	0.02	0.11	0.13	0.21	0.15	0.47	0.22
42	0.2	0.57	0.01	0.06	0.10	0.23	0.16	0.43	0.24	0.46	0.02	0.12	0.13	0.21	0.16	0.48	0.21
52	0.2	0.57	0.01	0.06	0.10	0.23	0.17	0.44	0.24	0.46	0.02	0.12	0.13	0.20	0.17	0.49	0.21
22	0.25	0.57	0.01	0.06	0.10	0.23	0.15	0.43	0.24	0.46	0.02	0.11	0.13	0.21	0.15	0.48	0.21
32	0.25	0.57	0.01	0.06	0.10	0.22	0.17	0.44	0.23	0.45	0.02	0.12	0.13	0.20	0.17	0.49	0.21
42	0.25	0.56	0.01	0.06	0.10	0.22	0.17	0.45	0.23	0.45	0.03	0.12	0.13	0.20	0.17	0.50	0.20
52	0.25	0.56	0.01	0.06	0.10	0.22	0.17	0.45	0.23	0.45	0.03	0.12	0.13	0.20	0.17	0.51	0.20
22	0.3	0.56	0.01	0.06	0.10	0.22	0.16	0.45	0.23	0.45	0.03	0.12	0.13	0.20	0.16	0.50	0.20
32	0.3	0.56	0.01	0.06	0.10	0.22	0.17	0.46	0.23	0.45	0.02	0.12	0.13	0.20	0.17	0.51	0.20
42	0.3	0.56	0.01	0.06	0.10	0.22	0.17	0.46	0.22	0.44	0.03	0.13	0.13	0.20	0.17	0.51	0.20
52	0.3	0.56	0.01	0.06	0.10	0.21	0.17	0.46	0.22	0.44	0.03	0.13	0.13	0.20	0.18	0.51	0.20

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the Dredge Efficiency Low simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – mean SSB relative to B_0; $0.1B_0$ and $0.2B_0$ – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den
40	80	0.69	0.00	0.03	0.12	0.37	0.04	0.21	0.41	0.63	0.01	0.05	0.18	0.35	0.02	0.17	0.38
50	80	0.71	0.00	0.03	0.12	0.39	0.03	0.17	0.43	0.65	0.01	0.05	0.18	0.38	0.01	0.14	0.40
60	80	0.73	0.00	0.03	0.12	0.41	0.03	0.15	0.44	0.68	0.01	0.05	0.19	0.40	0.01	0.12	0.41
70	80	0.74	0.00	0.03	0.12	0.43	0.02	0.13	0.45	0.70	0.01	0.04	0.19	0.42	0.01	0.10	0.43
40	90	0.69	0.00	0.03	0.12	0.35	0.04	0.21	0.39	0.61	0.01	0.06	0.18	0.34	0.02	0.18	0.36
50	90	0.71	0.00	0.03	0.12	0.38	0.03	0.18	0.41	0.64	0.01	0.05	0.18	0.37	0.02	0.14	0.38
60	90	0.73	0.00	0.03	0.12	0.40	0.03	0.15	0.42	0.67	0.01	0.05	0.19	0.39	0.01	0.12	0.40
70	90	0.74	0.00	0.03	0.12	0.42	0.03	0.14	0.44	0.70	0.01	0.05	0.19	0.42	0.01	0.11	0.42
40	100	0.69	0.00	0.04	0.11	0.34	0.04	0.22	0.38	0.60	0.01	0.05	0.17	0.34	0.02	0.18	0.35
50	100	0.71	0.00	0.03	0.12	0.36	0.03	0.18	0.40	0.64	0.01	0.05	0.18	0.36	0.01	0.15	0.37
60	100	0.72	0.00	0.03	0.12	0.39	0.03	0.16	0.41	0.67	0.01	0.05	0.18	0.39	0.01	0.12	0.39
70	100	0.73	0.00	0.03	0.12	0.41	0.03	0.14	0.42	0.68	0.01	0.05	0.19	0.41	0.01	0.11	0.41
40	110	0.69	0.00	0.04	0.11	0.33	0.04	0.23	0.37	0.61	0.01	0.06	0.17	0.33	0.02	0.18	0.35
50	110	0.70	0.00	0.03	0.12	0.36	0.03	0.19	0.38	0.63	0.01	0.05	0.18	0.36	0.02	0.15	0.37
60	110	0.71	0.00	0.03	0.12	0.38	0.03	0.16	0.40	0.65	0.01	0.05	0.18	0.38	0.01	0.13	0.39
70	110	0.74	0.00	0.03	0.12	0.40	0.03	0.14	0.41	0.68	0.01	0.05	0.19	0.41	0.01	0.11	0.40
40	120	0.69	0.00	0.04	0.11	0.33	0.04	0.23	0.36	0.60	0.01	0.06	0.17	0.33	0.02	0.19	0.34
50	120	0.70	0.00	0.04	0.12	0.35	0.03	0.20	0.37	0.63	0.01	0.05	0.17	0.35	0.02	0.15	0.36
60	120	0.72	0.00	0.03	0.12	0.37	0.03	0.16	0.39	0.66	0.01	0.05	0.18	0.38	0.01	0.12	0.38
70	120	0.73	0.00	0.03	0.12	0.40	0.03	0.15	0.40	0.67	0.01	0.05	0.18	0.40	0.01	0.11	0.40
Bt	Fmul																
22	0.1	0.72	0.00	0.04	0.12	0.42	0.04	0.18	0.41	0.66	0.01	0.06	0.18	0.37	0.03	0.19	0.38
32	0.1	0.70	0.00	0.04	0.12	0.40	0.06	0.22	0.40	0.64	0.01	0.07	0.18	0.35	0.04	0.23	0.37
42	0.1	0.69	0.01	0.04	0.12	0.38	0.07	0.24	0.39	0.62	0.02	0.07	0.18	0.33	0.05	0.26	0.35
52	0.1	0.68	0.01	0.04	0.11	0.35	0.08	0.26	0.38	0.59	0.02	0.07	0.17	0.31	0.06	0.29	0.34
22	0.15	0.69	0.00	0.04	0.11	0.35	0.06	0.25	0.35	0.60	0.01	0.07	0.17	0.31	0.05	0.26	0.32
32	0.15	0.68	0.01	0.04	0.11	0.34	0.07	0.26	0.35	0.59	0.02	0.07	0.17	0.30	0.05	0.29	0.31
42	0.15	0.67	0.01	0.04	0.11	0.33	0.08	0.28	0.34	0.58	0.02	0.07	0.16	0.29	0.06	0.31	0.31
52	0.15	0.66	0.01	0.04	0.11	0.32	0.08	0.29	0.33	0.57	0.02	0.08	0.16	0.28	0.06	0.32	0.30
22	0.2	0.67	0.01	0.04	0.11	0.31	0.07	0.28	0.32	0.57	0.02	0.07	0.16	0.28	0.06	0.31	0.29
32	0.2	0.66	0.01	0.04	0.11	0.31	0.08	0.29	0.31	0.56	0.02	0.08	0.16	0.28	0.06	0.32	0.28
42	0.2	0.66	0.00	0.04	0.11	0.30	0.08	0.30	0.31	0.56	0.02	0.08	0.16	0.27	0.06	0.33	0.28
52	0.2	0.65	0.01	0.04	0.11	0.30	0.09	0.31	0.31	0.55	0.02	0.08	0.16	0.27	0.07	0.34	0.28
22	0.25	0.65	0.00	0.04	0.11	0.30	0.08	0.31	0.30	0.55	0.02	0.08	0.15	0.27	0.06	0.33	0.28
32	0.25	0.65	0.01	0.04	0.11	0.29	0.08	0.31	0.30	0.55	0.02	0.08	0.15	0.27	0.07	0.34	0.27
42	0.25	0.65	0.01	0.04	0.11	0.29	0.09	0.32	0.30	0.55	0.02	0.08	0.15	0.27	0.07	0.34	0.27
52	0.25	0.65	0.01	0.04	0.11	0.29	0.09	0.32	0.30	0.54	0.02	0.08	0.15	0.26	0.07	0.35	0.27
22	0.3	0.65	0.01	0.04	0.11	0.29	0.08	0.32	0.29	0.55	0.02	0.08	0.15	0.26	0.07	0.34	0.27
32	0.3	0.65	0.01	0.04	0.11	0.29	0.09	0.32	0.29	0.54	0.02	0.08	0.15	0.26	0.07	0.35	0.26
42	0.3	0.64	0.01	0.04	0.11	0.29	0.09	0.33	0.29	0.54	0.02	0.08	0.15	0.26	0.07	0.35	0.26
52	0.3	0.65	0.01	0.04	0.11	0.29	0.09	0.33	0.29	0.54	0.02	0.08	0.15	0.26	0.07	0.35	0.26

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the Dredge Efficiency High simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – mean SSB relative to B_0; $0.1B_0$ and $0.2B_0$ – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den
40	80	0.67	0.00	0.04	0.12	0.37	0.07	0.27	0.43	0.60	0.01	0.07	0.18	0.32	0.04	0.26	0.38
50	80	0.68	0.00	0.04	0.12	0.38	0.05	0.25	0.44	0.61	0.01	0.06	0.18	0.34	0.03	0.23	0.39
60	80	0.69	0.00	0.04	0.12	0.40	0.04	0.23	0.45	0.63	0.01	0.06	0.18	0.35	0.03	0.20	0.40
70	80	0.70	0.00	0.03	0.12	0.41	0.04	0.20	0.45	0.65	0.01	0.05	0.19	0.36	0.02	0.17	0.41
40	90	0.65	0.00	0.04	0.11	0.34	0.07	0.29	0.41	0.57	0.01	0.07	0.17	0.31	0.04	0.29	0.36
50	90	0.66	0.00	0.04	0.11	0.35	0.05	0.27	0.42	0.59	0.01	0.06	0.18	0.32	0.03	0.25	0.37
60	90	0.68	0.00	0.04	0.12	0.37	0.04	0.24	0.43	0.60	0.01	0.06	0.18	0.33	0.03	0.22	0.38
70	90	0.69	0.00	0.04	0.12	0.38	0.04	0.22	0.43	0.62	0.01	0.06	0.18	0.35	0.02	0.19	0.39
40	100	0.64	0.00	0.04	0.11	0.32	0.08	0.32	0.39	0.55	0.02	0.07	0.17	0.29	0.05	0.30	0.34
50	100	0.66	0.00	0.04	0.11	0.33	0.06	0.29	0.40	0.57	0.01	0.06	0.17	0.31	0.04	0.26	0.35
60	100	0.66	0.00	0.04	0.11	0.34	0.05	0.26	0.41	0.59	0.01	0.06	0.17	0.32	0.03	0.23	0.36
70	100	0.68	0.00	0.04	0.12	0.36	0.04	0.23	0.42	0.60	0.01	0.06	0.18	0.34	0.02	0.20	0.37
40	110	0.64	0.01	0.04	0.11	0.30	0.08	0.33	0.37	0.54	0.02	0.08	0.16	0.28	0.05	0.32	0.33
50	110	0.64	0.00	0.04	0.11	0.31	0.07	0.30	0.38	0.56	0.01	0.07	0.17	0.29	0.04	0.27	0.34
60	110	0.66	0.00	0.04	0.11	0.33	0.05	0.27	0.39	0.57	0.01	0.06	0.17	0.31	0.03	0.24	0.35
70	110	0.68	0.00	0.04	0.11	0.34	0.04	0.24	0.40	0.59	0.01	0.06	0.17	0.33	0.02	0.20	0.36
40	120	0.63	0.01	0.04	0.11	0.29	0.08	0.34	0.36	0.54	0.02	0.08	0.16	0.27	0.06	0.33	0.31
50	120	0.64	0.00	0.04	0.11	0.30	0.07	0.31	0.37	0.55	0.01	0.07	0.16	0.28	0.04	0.29	0.33
60	120	0.65	0.00	0.04	0.11	0.31	0.05	0.29	0.38	0.56	0.01	0.06	0.17	0.30	0.03	0.25	0.34
70	120	0.67	0.00	0.04	0.11	0.32	0.05	0.25	0.39	0.58	0.01	0.06	0.17	0.32	0.03	0.21	0.35
Bt	Fmul																
22	0.1	0.71	0.00	0.04	0.12	0.39	0.05	0.19	0.39	0.64	0.01	0.06	0.18	0.35	0.03	0.21	0.36
32	0.1	0.70	0.00	0.04	0.12	0.38	0.06	0.22	0.39	0.63	0.01	0.06	0.18	0.34	0.04	0.23	0.35
42	0.1	0.68	0.01	0.04	0.12	0.37	0.07	0.24	0.38	0.61	0.02	0.07	0.17	0.33	0.06	0.27	0.34
52	0.1	0.66	0.01	0.04	0.11	0.35	0.09	0.27	0.37	0.60	0.02	0.08	0.17	0.31	0.07	0.30	0.33
22	0.15	0.66	0.01	0.04	0.11	0.31	0.08	0.29	0.32	0.56	0.02	0.07	0.16	0.28	0.06	0.30	0.29
32	0.15	0.65	0.01	0.04	0.11	0.30	0.09	0.31	0.31	0.55	0.02	0.08	0.16	0.27	0.07	0.33	0.29
42	0.15	0.64	0.01	0.05	0.11	0.30	0.10	0.32	0.31	0.54	0.02	0.09	0.15	0.26	0.08	0.35	0.28
52	0.15	0.63	0.01	0.05	0.11	0.29	0.11	0.33	0.31	0.53	0.02	0.09	0.15	0.26	0.10	0.37	0.27
22	0.2	0.63	0.01	0.04	0.11	0.27	0.10	0.35	0.28	0.52	0.02	0.08	0.15	0.25	0.08	0.37	0.26
32	0.2	0.62	0.01	0.04	0.10	0.27	0.11	0.36	0.28	0.51	0.02	0.09	0.15	0.24	0.10	0.38	0.25
42	0.2	0.62	0.01	0.05	0.10	0.26	0.12	0.37	0.28	0.51	0.02	0.10	0.14	0.24	0.11	0.39	0.25
52	0.2	0.61	0.01	0.05	0.10	0.26	0.12	0.38	0.27	0.50	0.02	0.10	0.14	0.24	0.12	0.41	0.25
22	0.25	0.61	0.01	0.05	0.10	0.26	0.11	0.38	0.27	0.50	0.02	0.09	0.14	0.24	0.10	0.40	0.24
32	0.25	0.61	0.01	0.05	0.10	0.25	0.12	0.39	0.26	0.49	0.02	0.10	0.14	0.23	0.11	0.42	0.24
42	0.25	0.60	0.01	0.05	0.10	0.25	0.13	0.40	0.26	0.49	0.02	0.10	0.14	0.23	0.12	0.42	0.24
52	0.25	0.60	0.01	0.05	0.10	0.25	0.13	0.40	0.26	0.49	0.02	0.10	0.14	0.23	0.12	0.43	0.23
22	0.3	0.60	0.01	0.05	0.10	0.25	0.12	0.40	0.26	0.49	0.02	0.09	0.14	0.23	0.11	0.42	0.24
32	0.3	0.60	0.01	0.05	0.10	0.24	0.13	0.40	0.25	0.49	0.02	0.10	0.14	0.22	0.12	0.43	0.23
42	0.3	0.59	0.01	0.05	0.10	0.24	0.14	0.41	0.25	0.48	0.02	0.10	0.14	0.22	0.12	0.43	0.23
52	0.3	0.59	0.01	0.05	0.10	0.24	0.14	0.41	0.25	0.48	0.02	0.11	0.14	0.22	0.13	0.44	0.23

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the Alternative Fishing simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – mean SSB relative to B_0; $0.1B_0$ and $0.2B_0$ – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den	SSB	$0.1B_0$	$0.2B_0$	Den
40	80	0.57	0.00	0.04	0.10	0.38	0.04	0.22	0.44	0.53	0.02	0.07	0.16	0.34	0.03	0.23	0.41
50	80	0.60	0.00	0.04	0.10	0.39	0.03	0.20	0.45	0.56	0.01	0.06	0.17	0.36	0.02	0.19	0.42
60	80	0.63	0.00	0.04	0.11	0.40	0.03	0.18	0.46	0.59	0.01	0.06	0.17	0.37	0.02	0.16	0.43
70	80	0.65	0.00	0.04	0.11	0.42	0.03	0.16	0.47	0.60	0.01	0.05	0.18	0.39	0.02	0.14	0.44
40	90	0.56	0.01	0.05	0.10	0.37	0.05	0.22	0.43	0.52	0.02	0.07	0.16	0.33	0.04	0.24	0.39
50	90	0.59	0.00	0.04	0.10	0.38	0.04	0.20	0.44	0.55	0.01	0.06	0.16	0.34	0.03	0.21	0.40
60	90	0.63	0.00	0.04	0.10	0.39	0.03	0.18	0.45	0.58	0.01	0.06	0.17	0.36	0.02	0.17	0.42
70	90	0.65	0.00	0.04	0.11	0.41	0.03	0.16	0.45	0.60	0.01	0.06	0.17	0.37	0.02	0.15	0.43
40	100	0.55	0.01	0.05	0.10	0.36	0.04	0.23	0.42	0.52	0.01	0.07	0.16	0.32	0.04	0.24	0.38
50	100	0.60	0.00	0.04	0.10	0.37	0.04	0.21	0.42	0.55	0.01	0.06	0.16	0.33	0.03	0.21	0.39
60	100	0.62	0.00	0.04	0.10	0.38	0.03	0.19	0.43	0.57	0.01	0.06	0.17	0.34	0.02	0.18	0.40
70	100	0.65	0.00	0.04	0.11	0.40	0.03	0.17	0.44	0.60	0.01	0.06	0.17	0.36	0.02	0.16	0.41
40	110	0.56	0.01	0.05	0.10	0.35	0.04	0.23	0.40	0.51	0.02	0.07	0.15	0.31	0.04	0.25	0.37
50	110	0.59	0.00	0.04	0.10	0.36	0.04	0.21	0.41	0.55	0.01	0.06	0.16	0.32	0.03	0.22	0.38
60	110	0.62	0.01	0.04	0.10	0.38	0.03	0.19	0.42	0.57	0.01	0.06	0.16	0.34	0.02	0.18	0.39
70	110	0.64	0.00	0.04	0.11	0.39	0.03	0.17	0.43	0.59	0.01	0.06	0.17	0.35	0.02	0.16	0.40
40	120	0.56	0.00	0.05	0.10	0.35	0.04	0.24	0.39	0.51	0.02	0.07	0.15	0.31	0.04	0.25	0.36
50	120	0.59	0.00	0.04	0.10	0.36	0.04	0.22	0.40	0.54	0.01	0.06	0.16	0.32	0.03	0.22	0.37
60	120	0.62	0.00	0.04	0.10	0.37	0.03	0.19	0.41	0.57	0.01	0.06	0.16	0.33	0.02	0.19	0.38
70	120	0.65	0.00	0.04	0.11	0.38	0.03	0.17	0.42	0.59	0.01	0.06	0.17	0.35	0.02	0.16	0.39
Bt	Fmul																
22	0.1	0.47	0.03	0.16	0.09	0.42	0.06	0.21	0.43	0.49	0.04	0.14	0.15	0.44	0.04	0.16	0.46
32	0.1	0.46	0.03	0.16	0.09	0.41	0.06	0.22	0.42	0.49	0.04	0.15	0.15	0.43	0.04	0.16	0.46
42	0.1	0.46	0.03	0.17	0.09	0.40	0.07	0.23	0.42	0.48	0.04	0.15	0.15	0.42	0.04	0.17	0.45
52	0.1	0.46	0.03	0.17	0.09	0.39	0.07	0.23	0.41	0.47	0.04	0.16	0.15	0.42	0.04	0.17	0.45
22	0.15	0.45	0.03	0.17	0.08	0.38	0.07	0.23	0.39	0.47	0.04	0.15	0.14	0.41	0.04	0.17	0.43
32	0.15	0.44	0.04	0.17	0.08	0.38	0.07	0.23	0.39	0.46	0.04	0.16	0.14	0.41	0.05	0.18	0.43
42	0.15	0.44	0.03	0.18	0.08	0.38	0.07	0.24	0.39	0.46	0.04	0.16	0.14	0.41	0.05	0.18	0.43
52	0.15	0.44	0.03	0.18	0.08	0.37	0.07	0.24	0.39	0.46	0.04	0.16	0.14	0.40	0.05	0.18	0.43
22	0.2	0.44	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.46	0.04	0.16	0.14	0.40	0.05	0.18	0.42
32	0.2	0.44	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.46	0.04	0.16	0.14	0.40	0.05	0.18	0.42
42	0.2	0.44	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
52	0.2	0.43	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
22	0.25	0.44	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
32	0.25	0.43	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
42	0.25	0.43	0.04	0.18	0.08	0.37	0.07	0.25	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
52	0.25	0.43	0.04	0.18	0.08	0.36	0.07	0.25	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
22	0.3	0.43	0.03	0.18	0.08	0.37	0.07	0.24	0.38	0.46	0.04	0.16	0.14	0.40	0.05	0.18	0.42
32	0.3	0.43	0.04	0.18	0.08	0.37	0.07	0.24	0.38	0.45	0.04	0.16	0.14	0.40	0.05	0.18	0.42
42	0.3	0.43	0.04	0.18	0.08	0.37	0.07	0.24	0.37	0.45	0.04	0.17	0.14	0.40	0.05	0.18	0.42
52	0.3	0.43	0.04	0.18	0.08	0.37	0.07	0.25	0.37	0.45	0.04	0.17	0.14	0.40	0.05	0.18	0.42

Appendix Table A2: Summary statistics for the Coromandel scallop sub-populations from the Castastrophic mortality simulations. Cl - *CPUElim*; TAC – *TACC*; Bt – *BaseTACC*; Fmul – *Fmult*; SSB – mean SSB relative to B_0; 0.1B_0 and 0.2B_0 – probability that SSB is less than 0.1 or 0.2 B_0; Den – mean density of legal-sized scallops.

RuleParam.		HG Sub-population				MI Sub-population				BP Sub-population				BI Sub-population			
Cl	TAC	SSB	0.1B_0	0.2B_0	Den	SSB	0.1B_0	0.2B_0	Den	SSB	0.1B_0	0.2B_0	Den	SSB	0.1B_0	0.2B_0	Den
40	80	0.65	0.01	0.07	0.11	0.36	0.06	0.26	0.38	0.57	0.01	0.08	0.16	0.33	0.05	0.23	0.35
50	80	0.67	0.01	0.06	0.11	0.37	0.05	0.23	0.39	0.60	0.01	0.08	0.17	0.35	0.04	0.20	0.36
60	80	0.69	0.01	0.06	0.11	0.38	0.05	0.20	0.40	0.62	0.01	0.07	0.17	0.36	0.03	0.17	0.37
70	80	0.70	0.01	0.06	0.11	0.40	0.04	0.18	0.41	0.63	0.01	0.07	0.17	0.38	0.03	0.15	0.38
40	90	0.64	0.01	0.06	0.10	0.33	0.07	0.27	0.37	0.56	0.01	0.08	0.16	0.31	0.05	0.25	0.33
50	90	0.66	0.01	0.06	0.11	0.35	0.06	0.24	0.38	0.59	0.01	0.08	0.16	0.34	0.04	0.20	0.35
60	90	0.67	0.01	0.06	0.11	0.37	0.05	0.21	0.39	0.60	0.01	0.07	0.17	0.35	0.04	0.18	0.36
70	90	0.69	0.01	0.06	0.11	0.38	0.05	0.19	0.40	0.62	0.01	0.07	0.17	0.37	0.03	0.16	0.37
40	100	0.63	0.01	0.06	0.10	0.32	0.07	0.28	0.35	0.55	0.02	0.08	0.15	0.31	0.05	0.26	0.32
50	100	0.66	0.01	0.06	0.11	0.34	0.06	0.25	0.36	0.57	0.01	0.08	0.16	0.33	0.04	0.22	0.34
60	100	0.67	0.01	0.06	0.11	0.35	0.05	0.22	0.37	0.59	0.01	0.07	0.16	0.35	0.04	0.18	0.35
70	100	0.69	0.01	0.06	0.11	0.37	0.05	0.20	0.38	0.61	0.01	0.07	0.17	0.37	0.03	0.16	0.36
40	110	0.63	0.01	0.06	0.10	0.31	0.07	0.29	0.34	0.55	0.02	0.08	0.15	0.30	0.05	0.26	0.31
50	110	0.64	0.01	0.06	0.10	0.32	0.06	0.26	0.35	0.56	0.01	0.08	0.16	0.32	0.04	0.22	0.33
60	110	0.66	0.01	0.06	0.11	0.34	0.05	0.23	0.36	0.59	0.01	0.07	0.16	0.34	0.04	0.19	0.34
70	110	0.68	0.01	0.06	0.11	0.36	0.05	0.20	0.37	0.61	0.01	0.07	0.16	0.36	0.03	0.16	0.36
40	120	0.62	0.01	0.07	0.10	0.30	0.07	0.30	0.33	0.54	0.01	0.08	0.15	0.30	0.05	0.27	0.30
50	120	0.64	0.01	0.06	0.10	0.32	0.06	0.27	0.34	0.56	0.01	0.08	0.15	0.32	0.04	0.23	0.32
60	120	0.66	0.01	0.06	0.11	0.33	0.05	0.24	0.35	0.58	0.01	0.07	0.16	0.34	0.04	0.19	0.33
70	120	0.67	0.01	0.06	0.11	0.35	0.05	0.21	0.36	0.60	0.01	0.07	0.16	0.36	0.03	0.17	0.35
Bt	Fmul																
22	0.1	0.68	0.01	0.06	0.11	0.40	0.06	0.20	0.38	0.62	0.01	0.08	0.17	0.37	0.05	0.21	0.35
32	0.1	0.67	0.01	0.07	0.11	0.39	0.07	0.24	0.37	0.60	0.02	0.08	0.16	0.35	0.07	0.24	0.34
42	0.1	0.64	0.01	0.07	0.11	0.37	0.08	0.26	0.36	0.58	0.02	0.09	0.16	0.33	0.08	0.28	0.33
52	0.1	0.63	0.01	0.07	0.10	0.35	0.10	0.28	0.35	0.56	0.02	0.10	0.16	0.31	0.08	0.31	0.31
22	0.15	0.64	0.01	0.07	0.10	0.32	0.08	0.28	0.32	0.56	0.02	0.09	0.15	0.30	0.07	0.29	0.29
32	0.15	0.63	0.01	0.07	0.10	0.32	0.09	0.29	0.31	0.55	0.02	0.10	0.15	0.29	0.08	0.31	0.29
42	0.15	0.62	0.01	0.07	0.10	0.31	0.10	0.31	0.30	0.54	0.02	0.11	0.15	0.28	0.09	0.33	0.28
52	0.15	0.61	0.01	0.07	0.10	0.30	0.11	0.32	0.30	0.52	0.02	0.11	0.14	0.27	0.10	0.35	0.27
22	0.2	0.62	0.01	0.07	0.10	0.29	0.10	0.32	0.28	0.52	0.02	0.10	0.14	0.27	0.08	0.34	0.26
32	0.2	0.61	0.01	0.07	0.10	0.29	0.10	0.33	0.28	0.51	0.02	0.11	0.14	0.26	0.09	0.36	0.26
42	0.2	0.60	0.01	0.07	0.10	0.28	0.11	0.34	0.28	0.51	0.02	0.11	0.14	0.26	0.10	0.37	0.25
52	0.2	0.60	0.01	0.07	0.10	0.28	0.12	0.35	0.27	0.51	0.02	0.11	0.14	0.25	0.10	0.38	0.25
22	0.25	0.61	0.01	0.07	0.10	0.28	0.11	0.35	0.27	0.51	0.02	0.11	0.14	0.26	0.09	0.37	0.25
32	0.25	0.60	0.01	0.07	0.10	0.27	0.11	0.36	0.26	0.50	0.02	0.11	0.14	0.25	0.10	0.38	0.24
42	0.25	0.59	0.01	0.07	0.10	0.27	0.12	0.36	0.26	0.50	0.02	0.11	0.14	0.25	0.10	0.39	0.24
52	0.25	0.59	0.01	0.07	0.10	0.27	0.12	0.37	0.26	0.49	0.02	0.11	0.13	0.25	0.11	0.40	0.24
22	0.3	0.60	0.01	0.07	0.10	0.27	0.11	0.36	0.26	0.50	0.02	0.11	0.14	0.25	0.10	0.38	0.24
32	0.3	0.59	0.01	0.07	0.10	0.27	0.12	0.37	0.25	0.49	0.02	0.11	0.13	0.24	0.11	0.40	0.23
42	0.3	0.59	0.01	0.07	0.10	0.27	0.12	0.37	0.25	0.49	0.02	0.11	0.13	0.24	0.11	0.40	0.23
52	0.3	0.59	0.01	0.07	0.10	0.26	0.12	0.37	0.25	0.50	0.02	0.12	0.13	0.24	0.11	0.40	0.23

APPENDIX B. ADDITIONAL ANALYSES FOR THE COROMANDEL SCALLOP MSE.

At the 7 April 2010 meeting, the SFWG requested a few additional analyses for the Coromandel scallop MSE. Specifically, the requests were:

- Conduct *Survey* rule simulations with an asymptotic dredge efficiency
- Impose a minimum CPUE limit on the *Survey* decision rules. The limit should be set at the 3rd percentile of the historical distribution of commercial CPUE (CPUE calculated by month and by bed to mimic the operating model)
- Conduct a *Survey* rule run with a 0 base TACC.
- Ascertain if the operating model produces CPUE hyperstability similar to the pattern observed in the survey and fishery density data (see **Error! Reference source not found.** below). If not, modify the model so that CPUE hyperstability is similar to the observed pattern.
- Investigate why stock risk is so high for the survey-based rules relative to the *LimitCPUE* rules.

Results of these additional analyses are presented here.

Asymptotic selectivity

The simulated asymptotic dredge efficiencies are shown in Figure B1 .They follow the same form as those used in the base model except for the right hand limbs which are asymptotic.

Results from the asymptotic dredge efficiency simulations are shown in Figure B2. For both the *Survey* and *LimitCPUE* rules, the asymptotic dredge efficiency assumption results in higher mean catch but for the *Survey* rules the probability of stock abundance less than 20% B_0 decreases whereas this metric increases for the *LimitCPUE* rules. The increase in mean catch results from a decrease in incidental mortality with the asymptotic dredge efficiency. For the *Survey* rules the lower incidental mortality results in a lower stock risk associated with catching a particular TACC whereas for the *LimitCPUE* rules the higher catch rate associated with asymptotic dredge efficiency results in higher risk.

The change in risk is not great for either set of rules with the probability of stock abundance less than 20% B_0 increasing by an average of 0.014 for *LimitCPUE* rules and decreasing by an average of 0.001 for *Survey* rules.

Survey rule with a CPUE limit

Commercial CPUE data (1995–2008) was summarized by statistical area and month to estimate quantiles of the distribution. The 0.03 quantile of the distribution was 26.6 kg/hr (Table B1). A CPUE limit was imposed on the *Survey* decision rules with the CPUE limit set at 26.6 kg/hr. The limit was imposed as in the *LimitCPUE* rules; that is, when the CPUE limit is breached the fishing bed is not fished for the remainder of the season.

Results from the *Survey* rule with a CPUE limit are shown in Figure B3. With a minimum CPUE limit the probability of stock abundance less than 20% B_0 decreases relative to the base case simulations, in particular for the higher-catch rules. Across rules, the decrease in stock risk ranges from 0.008 to 0.283.

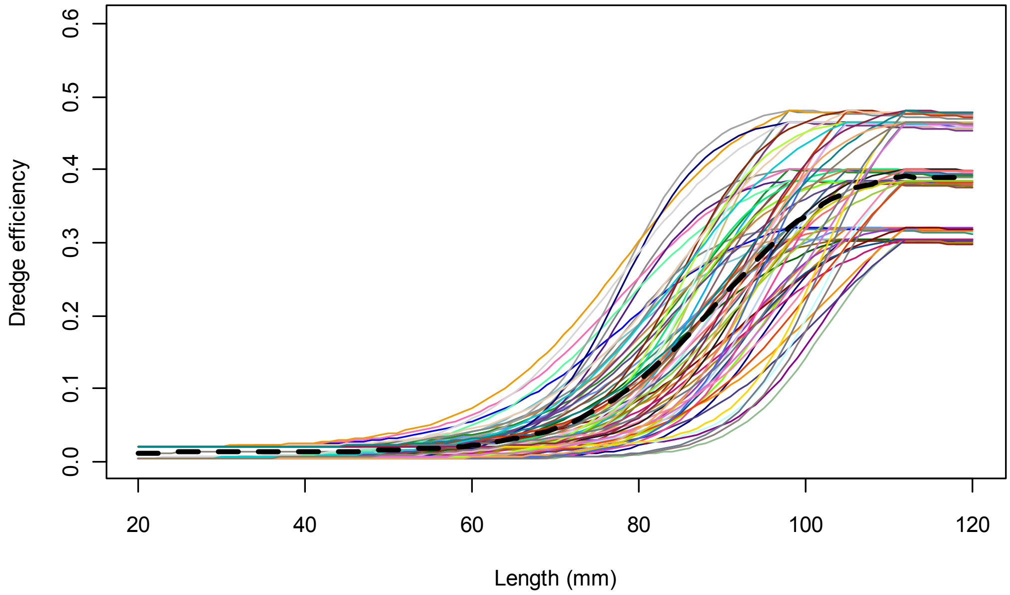

Figure B1: Simulated asymptotic (almost) dredge efficiency.

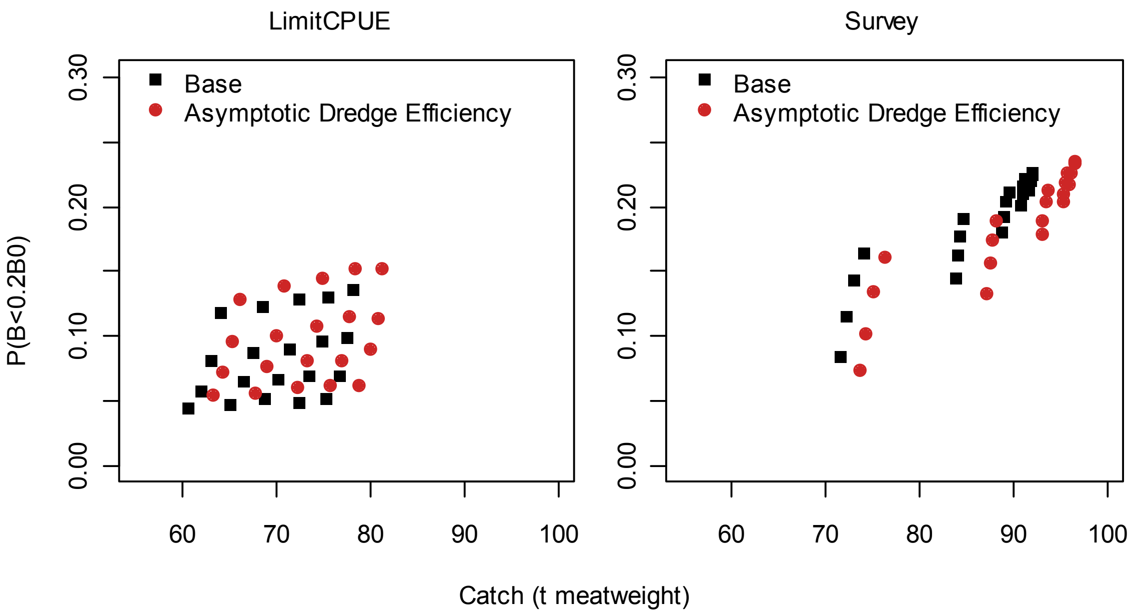

Figure B2: Probability of spawning stock biomass below 20%B_0 versus mean catch for *Survey* based decision rules run under base case and asymptotic dredge efficiency assumptions (left panel), and base case and CPUElimit assumptions (right panel).

Table B1: Quantiles of the distribution of commercial fishery CPUE (summarized by statistical area and month).

					Quantile
0.01	0.02	0.03	0.05	0.50	0.95
13.8	18.1	26.6	35.2	101.0	292.1

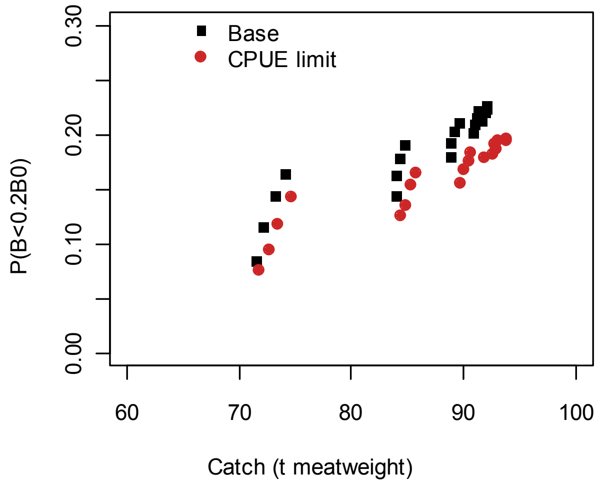

Figure B3: Probability of spawning stock biomass below 20%B_0 versus mean catch for *Survey* based decision rules run under base case and CPUE limit assumptions.

Survey rule with 0 base TACC

A survey rule with a *baseTACC* of 0 was run (the *baseTACC* for the other decision rules ranged from 22 to 52 t). The probability of stock biomass falling below 20%B_0 is lower with the 0 *baseTACC* run, in particular for runs with higher exploitation rates (Figure B4).

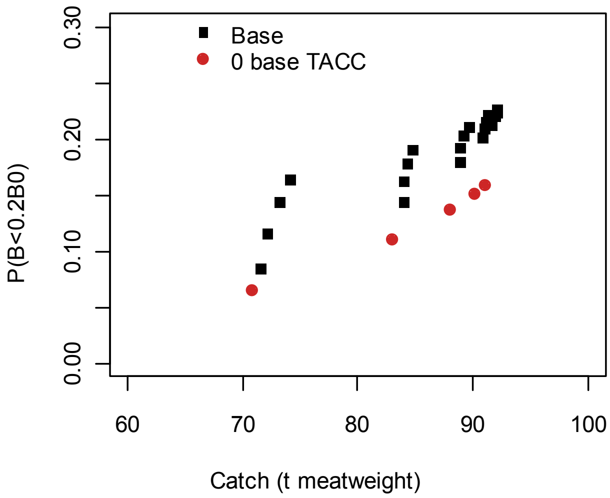

Figure B4: Probability of spawning stock biomass below 20%B_0 versus mean catch for *Survey* decision rules run under the base case and a run with a 0 base TACC.

Stock risk for *Survey* rules

The question remains: why do the Survey decision rules perform so poorly on the risk criterion (probability of stock biomass below 20% B_0) relative to the *LimitCPUE* rules? For the original MSE analyses the range in stock risk was similar between the *Survey* and *LimitCPUE* decision rules. Between the original operating model and the current version there have been a number of changes, all of which contribute somewhat to the risk performances of alternative decision rules.

The revised operating model has slower growth, with scallops taking about 0.5 years longer to reach a size of 100 mm. This change was made so that there would be better agreement between simulated and actual survey size distributions (Figure B5). The slower growth results in substantially higher incidental mortality, with incidental fishing effects creating mortalities of 80% of landings and higher for fishing mortality rates of 0.2 and higher.

Operating model runs where incidental fishing mortality rates were set at 50% of the base case values resulted in substantially lower stock risk for both the *Survey* and *LimitCPUE* rules (Figure B6).

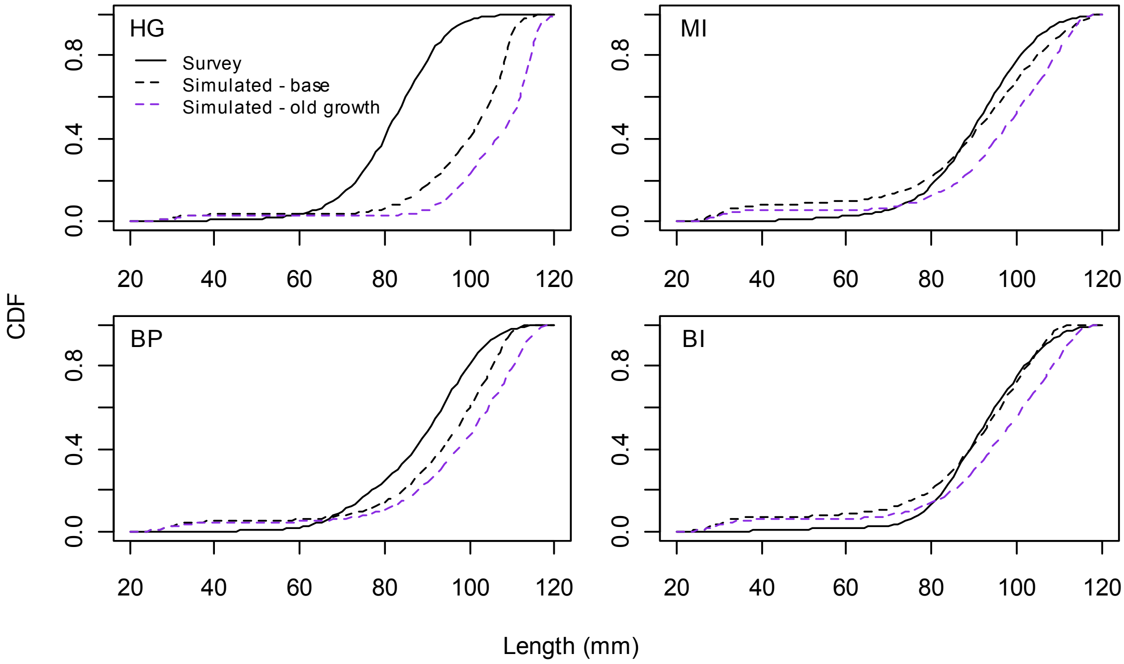

Figure B5: Cumulative density function for the scallop survey length frequency data (1993–2008) and simulated survey length frequencies from original and current model growth, by sub-population.

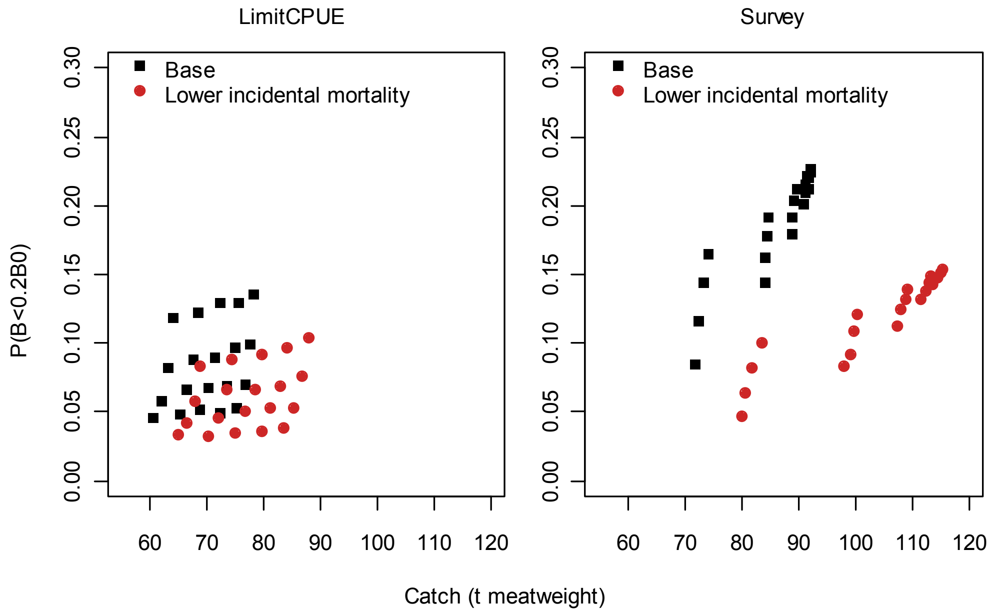

Figure B6: Probability of stock biomass below 20%B_0 versus mean catch for *LimitCPUE* and *Survey* rules run under Base case and lower incidental mortality assumptions (50% of the base case assumptions).

CPUE hyperstability

To get an idea of the degree to which fishers can maintain higher catch rates within a scallop bed by fishing areas within the bed that have higher density, the scallop survey data were analysed to determine the degree of density variation within a bed. All survey data with 9 or more dredge stations were selected, resulting in 52 data sets (scallop bed and year, 1995 – 2008). For each data set the station density estimates were sorted into three groups representing the lowest, middle and highest thirds of the densities, consistent with the operating model where each scallop bed has 3 sub-beds that differ in their scallop density. The means and medians of the density CVs within each density category and the ratios of densities among the density categories are shown in Table B2.

Table B2: The mean and median CV of density within scallop beds subdivided into density groups (lowest third, mid third and highest third, within each bed), and the mean and median ratio of densities among the density groups.

	CV of density within group			Ratio of densities
	Low 33%	Mid 33%	High 33%	Low:Mid:High
Mean	0.84	0.39	0.41	0.06:0.23:0.71
Median	0.77	0.37	0.37	0.04:0.24:0.72

Assuming a normal distribution, the density CVs imply that within the high- and mid-density areas of the bed the mean densities for the area with the highest and lowest 50% of the densities differ by a factor of about 1.9. (For the low-density sub-beds the ratio of mean densities between the highest 50% and lowest 50% of densities is 2.5).

The scallop MSE operating model assumes average density ratios of 1:3:6, which differs somewhat from those observed in the scallop survey data.

A comparison of the mean scallop density (gm/m^2) observed in surveys with mean scallop densities implied by commercial fishery CPUE (adjusting catch rates on the assumptions of 2 m dredge width and 2.54 knots dredging speed) suggests hyperstability in the fishery CPUE (Figure B7). When mean survey densities are above 15 gm/m^2 the ratio of fishery densities to survey densities is generally around 1. As mean survey densities decrease, the ratio of fishery density to survey density increases, and at survey densities around 1 gm/m^2 the ratio has been as high as 13. However, ratios of fishery density to survey density above 5 are all associated with small amounts of fishing effort (and hence catch), suggesting that the areas being fished are small pockets of higher density that cannot support much effort or catch.

The ratios of fishery to survey densities from simulations of the scallop base operating model under a *Survey* rule (0.2 exploitation rate) are shown in Figure B8. While there is an increase in the fishery density relative to the survey density at low abundance, the pattern is not nearly as extreme in the actual fishery data. The average ratio of fishery density to survey density is only about 2 at low survey density. There are some differences between the simulator and fishery that may account for these differences: in the simulator surveys are not conducted at densities below 0.6 scallops per square metre; the fishery continues at low catch rates (for survey rules), and the sub-beds are simulated with homogeneous densities so there are no areas of very high density.

To further investigate the hyperstability properties of the operating model, a few changes were made to make the simulator more similar to the actual fishery. A minimum CPUE limit was added to the operating model (26.6 kg/hr), scallop surveys were conducted at lower densities (0.1/m^2) to generate simulated observations at lower mean densities, and an additional "high density" bed was added to each of the sub-populations. The high density beds were constructed by removing a small fraction of the area from one bed (1% – 2% of the bed, except for HG which was 8%) and putting 20% of the recruitment from the original bed into the smaller bed and 80% of the recruitment into the larger bed.

With relatively small areas of higher densities in the simulated scallop bed structure, the ratios of fishery to survey density are much higher at low survey densities (Figure B9) increasing to 5 or higher at low abundance. With surveys occurring at lower densities, there are more observations at lower densities, and the CPUE limit decreases the number of observations where there is low survey density and low fishery density. The pattern of hyperstability in the simulations is similar to that in the actual data (compare Figure B7 and Figure B9). In the actual fishery it appears that small amounts of effort can be directed to areas of locally high density so that catch rates can remain high at low average density, but there is no indication that the locally high density areas can support much fishing effort. For the *LimitCPUE* rules, the mean catch and stock risk (probability of stock biomass below 20% B_0) are similar for the base model and for the high density scallop bed scenario (Figure B10).

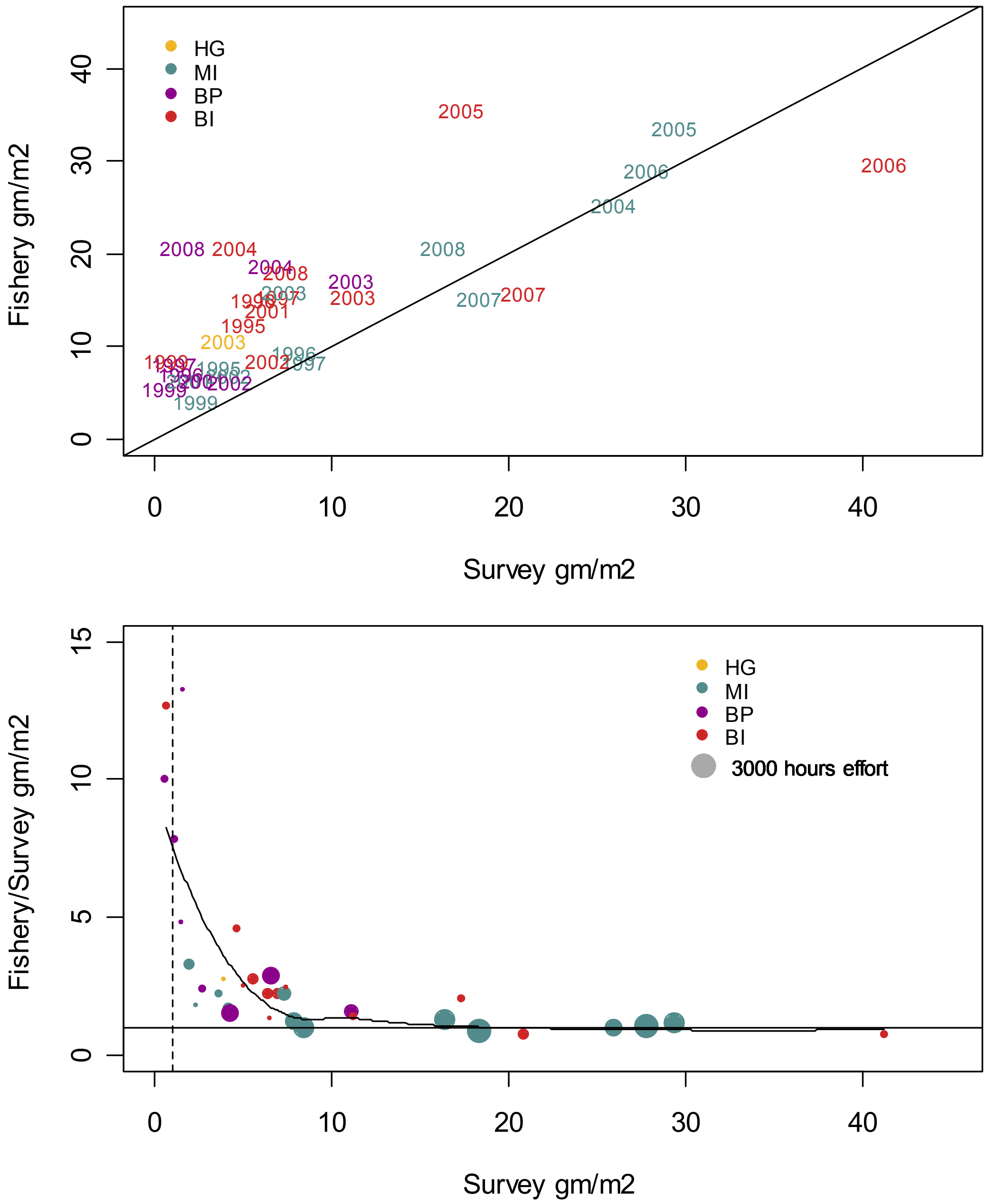

Figure B7: Estimates of scallop densities encountered in commercial fisheries (g/m^2) versus survey estimates of scallop densities (g/m^2) in upper panel. The lower panel shows the same data but expresses fishery densities as a fraction of the survey densities. Symbol sizes are proportional to the amount of effort (hours) in commercial fishery in the sub-population and year. The horizontal line is drawn to show the 1:1 relationship; the dashed vertical line shows where the mean survey density is 1 g/m^2, and the curved line shows a loess fit to the data points, weighted by the amount of effort.

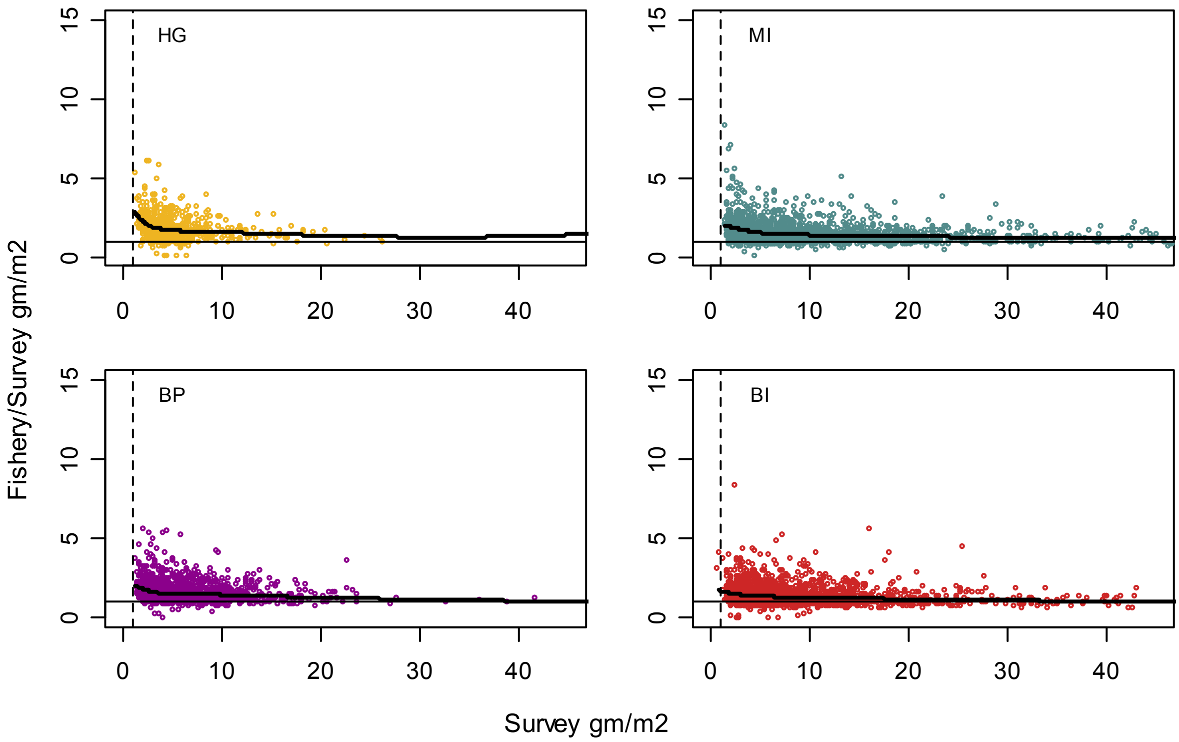

Figure B8: Simulated fishery and survey densities (fishery densities expressed as fractions of survey densities) from a *Survey* decision rule (*Fmult*=0.2). The horizontal line is drawn to show the 1:1 relationship and the dashed vertical line shows where the mean survey density is 1 g/m^2. The curved line is a loess smooth through the data points, weighted by the amount of effort.

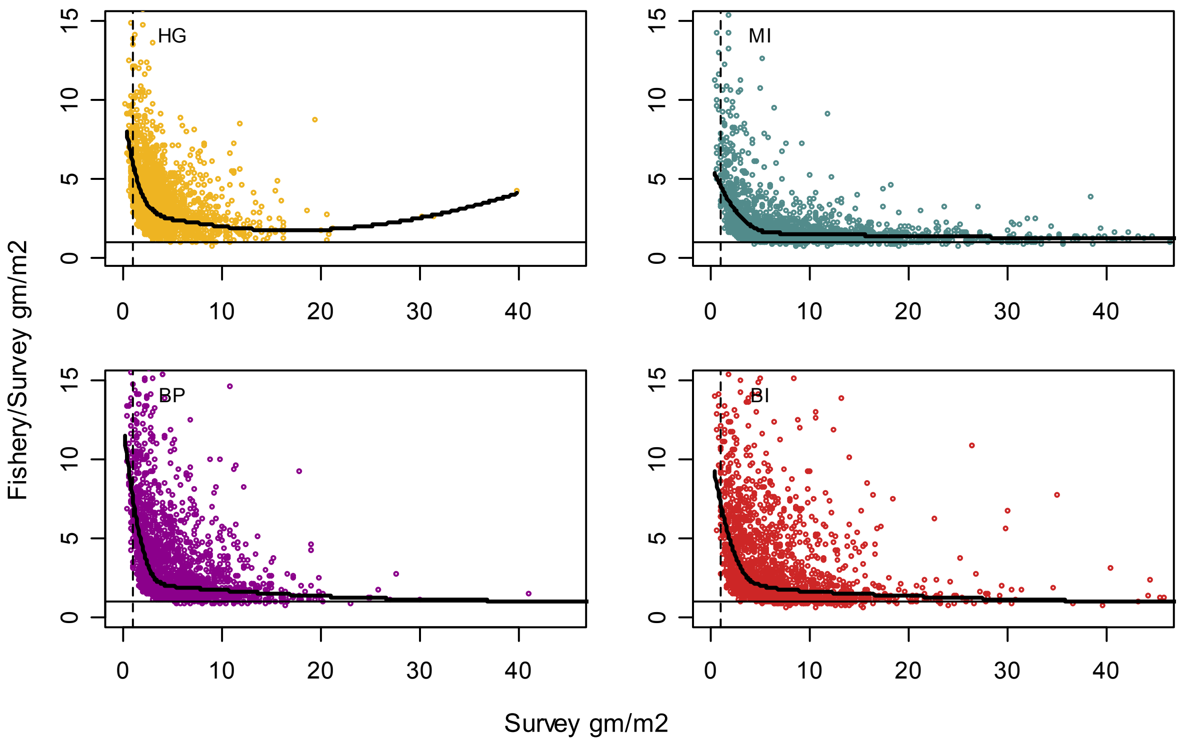

Figure B9: Simulated fishery and survey densities (fishery densities expressed as fractions of survey densities) from a *Survey* decision rule (*Fmult*=0.2) with a minimum CPUE limit, additional high density beds, and surveys conducted at lower density limits (0.01/m^2). The horizontal line is drawn to show the 1:1 relationship, the dashed vertical line shows where the mean survey density is 1 m/m^2, and the solid black curve is a weighted loess smooth, weighted by the amount of effort.

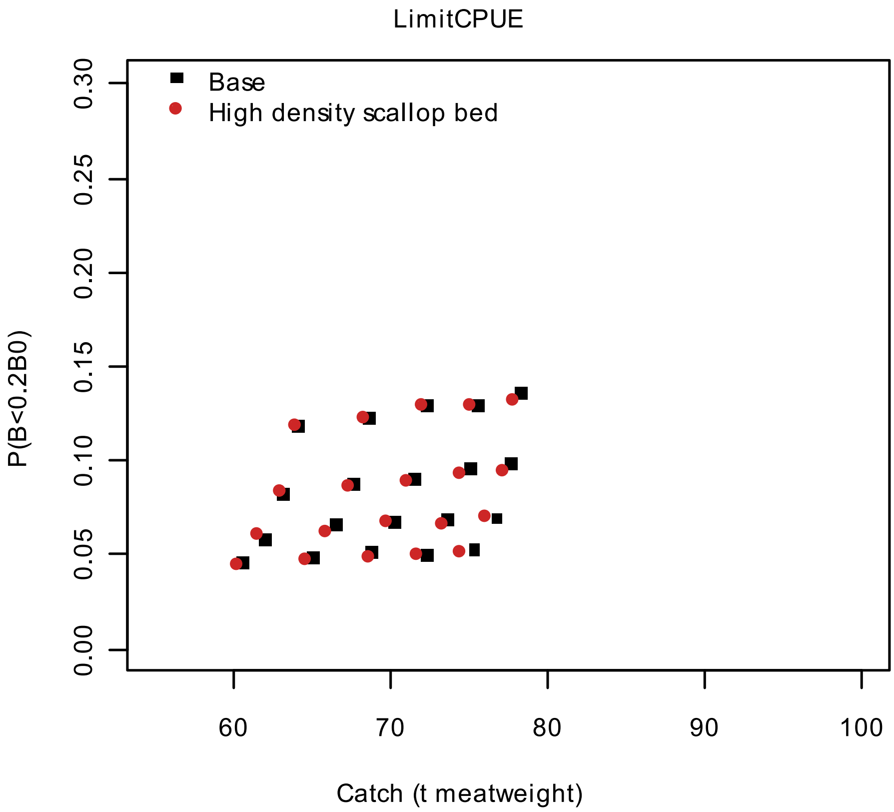

Figure B10: Probability of stock biomass below 20%B_0 versus mean catch for *LimitCPUE* rules run under Base case and the high density scallop bed assumptions.

APPENDIX C. UP-DATED ANALYSES BASED ON THE REVISED DREDGE EFFICIENCY ESTIMATES.

The dredge efficiency assumptions used for the original Coromandel scallop MSE work were based on analyses of dredge efficiency experimental data reported in Cryer & Parkinson (2006). The experimental data have been re-analysed, and the revised set of dredge efficiency relationships (Bian et al. 2010) have been accepted as the best available estimates of dredge efficiency for Coromandel scallops. This appendix reports on additional MSE model runs that incorporate the revised dredge efficiency estimates.

Revised dredge efficiency

The new dredge efficiency analyses resulted in unique relationships between Coromandel scallop dredge efficiency and scallop length for each combination of substrate type (sand or mud/silt), depth category (four levels), and whether or not a dredge tow is terminated (Bian et al. 2010). Dredge efficiencies are higher in mud/silt, at greater depths, and when a tow is not terminated (Figure C1). It should be noted that the Bian et al. (2006) analysis used a backward model selection approach, starting with the most complex model and sequentially removing a covariate. If a forward model selection approach had been used the model selected would have only included the depth covariate.

The MSE simulator assumes variability (unbiased) in the dredge efficiency parameters, which is represented as 73 alternative dredge efficiency relationships (Figure C1). For model runs based on the revised dredge efficiency estimates, the same structure with 73 alternative dredge efficiencies is retained. 72 of the alternative dredge efficiencies are simulated by repeating the set of 16 dredge efficiency relationships: the 4 non-terminated sand relationships are each repeated 11 times; the 4 non-terminated mud/silt relationships are each repeated 3 times: the 4 terminated sand relationships are each repeated 3 times: the 4 terminated mud/silt relationships are repeated just once. One additional dredge efficiency relationship, estimated as the average efficiency over the other 72 relationships, is assumed to represent the average dredge efficiency behaviour.

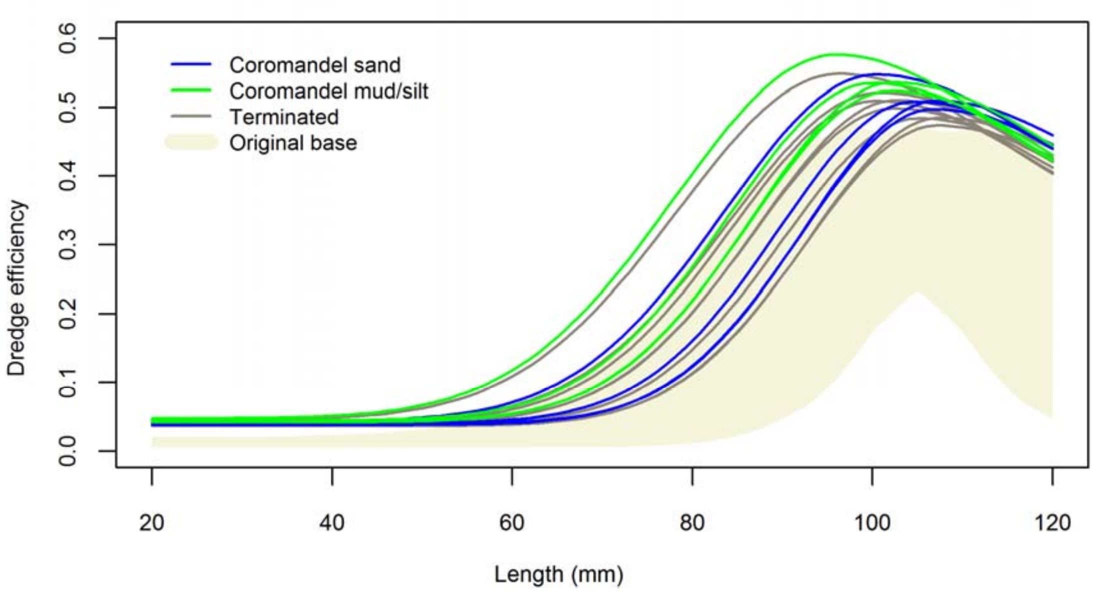

Figure C1: Dredge efficiency at length for the revised and original (base case) dredge efficiency models: the "original base" shows the 95% limits assumed for the original base case operating model; the "Coromandel sand" and "Coromandel mud/silt" relationships are for four depth intervals and non-terminated tows; and the "Terminated" tow relationships repeat the Coromandel sand and Coromandel mud/silt at depth relationships for terminated tows.

Re-tuning the operating model and equilibrium dynamics

The base case operating model was tuned to fishery data by doing simulations over a range of constant fishing mortality rates and adjusting R_0 so that model-predicted average catch and average CPUE were consistent with estimates from the fishery. Re-tuning the model with the revised dredge efficiency estimates suggests a $\ln(R_0)$ of 18.3, whereas the value for the original dredge efficiency was 18.6 (Figure C2). With the higher dredge efficiency, the apparent stock size is smaller (B_0 and R_0 at 74% of original) and historic fishing mortality rates are higher.

With the re-tuned base case model and revised dredge efficiency estimates, equilibrium dynamics were modelled to determine how productivity characteristics of the simulated population had changed with the changes. Simulations were deterministic (in terms of recruitment variation) but include catastrophic mortality events.

The MSY estimate is similar to that of the original base case but fishery-induced incidental mortality is much reduced (Figure C3).

For the revised model, the fishing mortality that generates MSY is 0.55, compared to 0.40 for the original base case. When fishing at F_{msy} spawning stock biomass is 32% of the unexploited level and the probability of stock biomass below 20% B_0 is 8.9%. For the original base case, fishing at F_{msy} resulted in spawning stock biomass at 33% of the unexploited level and a 7.5% probability of stock biomass below 20% B_0.

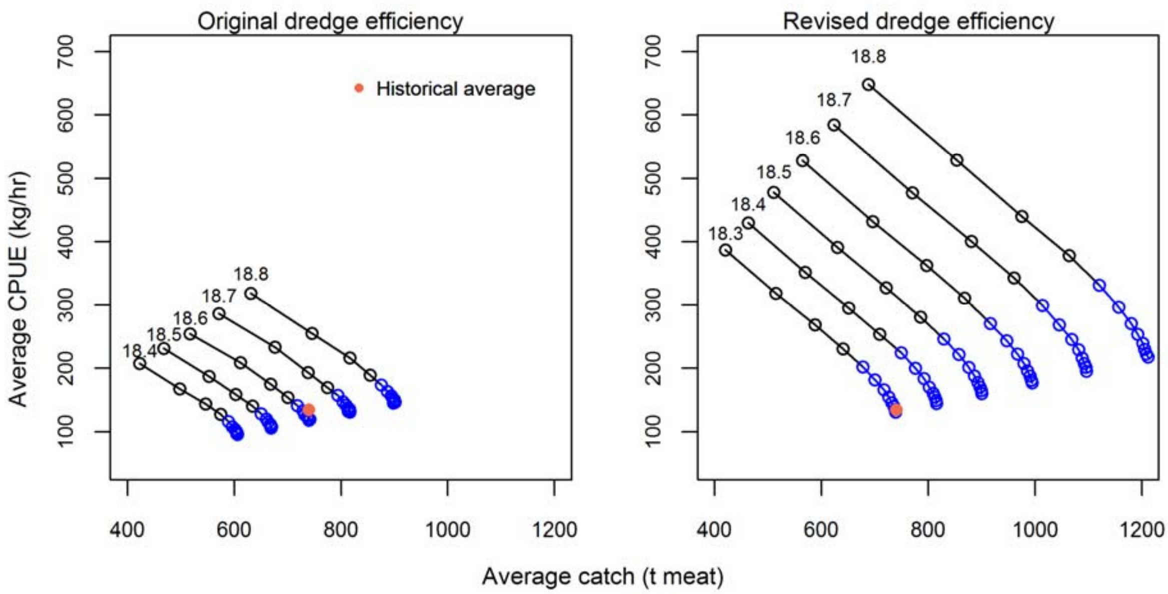

Figure C2: Estimates of average CPUE (kg/hr) versus average catch (t meatweight) at alternative values of $\ln(R_0)$ and exploitation rates (ranging from 0.08 to 0.40). The blue points indicate exploitation rates from 0.2 to 0.4. Results are based on assuming either the original dredge efficiency (left panel) or the revised dredge efficiency (right panel) estimates.

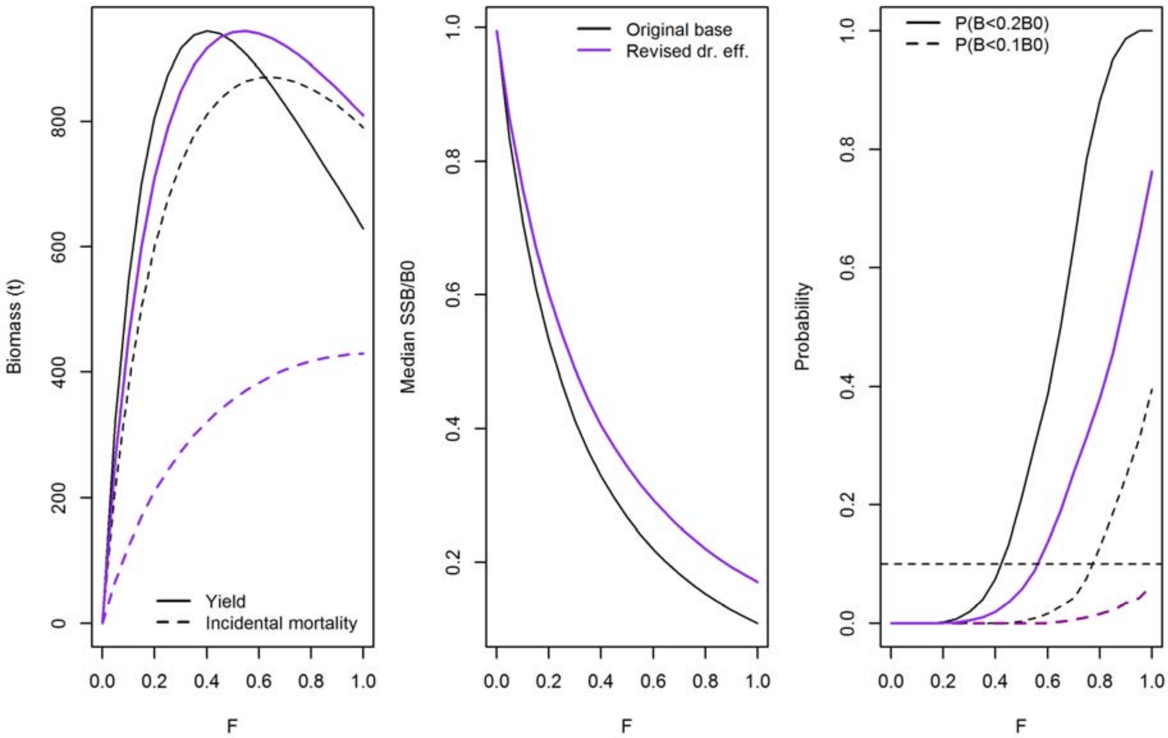

Figure C3: Results from deterministic simulations at fixed fishing mortality (*F*) values for the original base case (black) and the revised dredge efficiency (purple) models: Yield and incidental mortality; Spawning stock biomass relative to B_0; and probabilities of stock biomass falling below 10% and 20% B_0.

Revised dredge efficiency runs for *LimitCPUE* and *Survey* rules

The revised dredge efficiency model was run for the *LimitCPUE* and *Survey* decision rules over the range of rule parameter values used for the original analyses.

For the *LimitCPUE* rules, average catch increases slightly with a considerable increase in stock risk (probability of stock biomass being below 20% B_0) for a given rule (Figure C4). All rules with a 70 kg/hr CPUE threshold for closing beds (*CPUElim*) result in less than 10% stock risk. With the revised dredge efficiency estimates, a given CPUE level reflects a lower scallop density. Although the unexploited stock abundance is also reduced for this run, the reduction in density associated with a CPUE appears to be greater. For all *LimitCPUE* rules, the probability of stock biomass being below 10% B_0 is very small (< 0.6%).

For the *Survey* decision rules, the average catch is considerably lower for the revised dredge efficiency runs than for the original base case (Figure C4). For a given level of catch, stock risks are similar for the revised dredge efficiency runs and the original base case except for runs with higher *BaseTACC*.

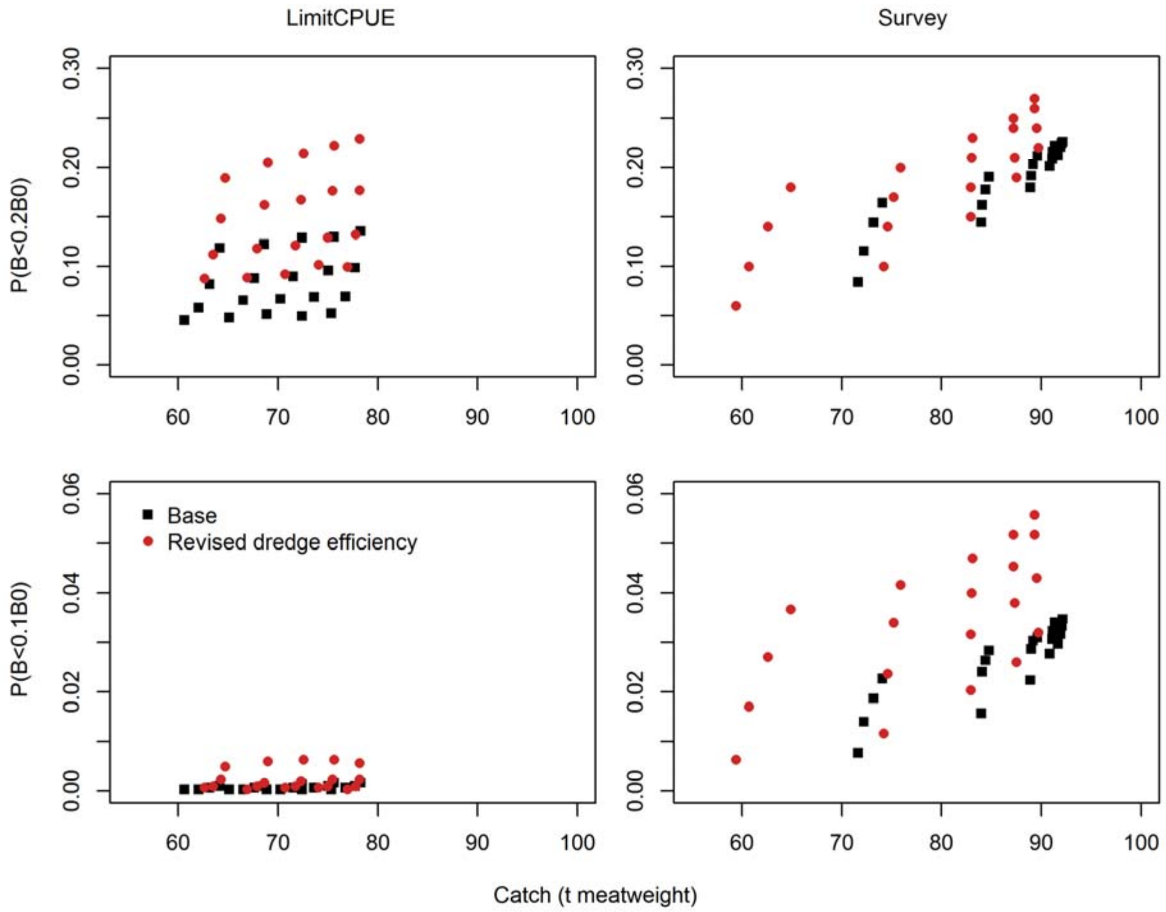

Figure C4: Probability of stock biomass being below 20%B_0 and below 10%B_0 versus mean catch for *LimitCPUE* and *Survey* rules run under the original Base case and revised dredge efficiency assumptions.

APPENDIX D: BIENNIAL AND TRIENNIAL SURVEYS

Introduction

The original management strategy evaluation (MSE) conducted for the Coromandel scallop fishery evaluated two approaches for setting total allowable commercial catches (TACCs) and managing the fishery. The first approach, based on the current management system, sets a low base TACC which can be increased in-season based on the results of a resource survey (*Survey* rule). The second approach sets higher TACCs and closes individual scallop beds when catch rates (CPUE) fall below a specified threshold level (*LimitCPUE* rules).

A third option for setting TACCs, a variant of the first approach, is to conduct surveys less frequently than annually and maintain the survey-based TACC for the years between surveys. Simulations conducted with biennial and triennial surveys were conducted and are reported here.

Methods

All aspects of the simulations, other than replacing annual surveys with less frequent surveys, were the same as those for the baseline *Survey* decision rules. The biennial and triennial survey harvest control rules were implemented as follows:

For years (y) when a survey is conducted:
1) At the beginning of the season, set a base TACC (*BaseTACC*).
2) Conduct a survey and calculate the survey rule-based TACC. If the survey rule-based TACC is higher than the base TACC, increase the TACC. The TACC for the year ($TACC_y$) is thus the greater of the base TACC and the survey rule-based TACC.

For years (y) when no survey is conducted:
1) Set the TACC ($TACC_y$) equal to the previous years' TACC ($TACC_{y-1}$) at the beginning of the season.

As in the baseline *Survey* decision rules, rule parameter were: *BaseTACC* values ranging from 22 to 52 t meatweight, and survey multipliers used to calculate the rule-based TACC (*Fmult*) ranging from 0.1 to 0.3.

Results

Mean catch decreases for *Survey* rules simulated with biennial or triennial surveys, relative to the catches attained with the same decision rule and annual surveys (Figure D1). The reductions in mean catches are not large, averaging 1% and 3% for biennial and triennial surveys, respectively. Stock risk, measured as the probability that spawning stock biomass falls below 20% of its unfished level, increases with less frequent surveys when the simulated decision rules are not highly aggressive – that is, decision rules that result in lower average catches (Figure D1). For the decision rules resulting in higher average catches, stock risk is lower when biennial or triennial surveys are simulated than when annual surveys are simulated. Overall, the influence of survey frequency on stock risk is not large (Figure D3).

The result that a reduction in survey frequency has minimal effect on stock risk is not expected. In part, the reason for this that there is a high degree of autocorrelation in both TACCs and catches when annual surveys are simulated (Figure D2, Table D1). Patterns in TACCs and catches do not change much with decreased survey frequency. With reduced survey frequency, autocorrelation in the simulated TACCs increases but autocorrelation in simulated catches does not increase (Table D1). The autocorrelations in simulated TACCs and catches are similar to those observed historically in the Coromandel scallop fishery (Table D1).

Table D1: Autocorrelation (one year lag) in simulated TACCs and catches when surveys are simulated at alternative frequencies (averaged over all decision rules), and autocorrelation in the SCA CS fishery TACCs (1992 – 2009) and catches (1980 -2009).

	TACC	Catch
Simulated survey frequency:		
Annual	0.61	0.67
Biennial	0.68	0.67
Triennial	0.73	0.68
SCA CS fishery	0.72	0.68

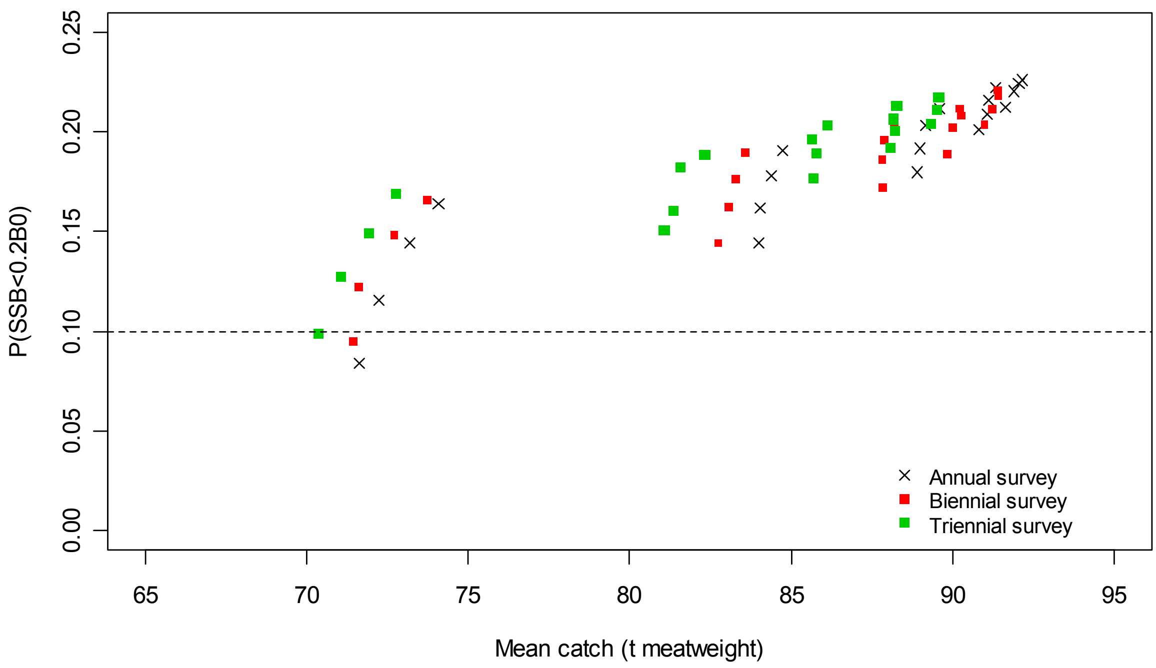

Figure D1: Comparison of mean catch and stock risk (P[SSB<0.2B_0]) for *Survey* decision rules run with annual, biennial and triennial surveys.

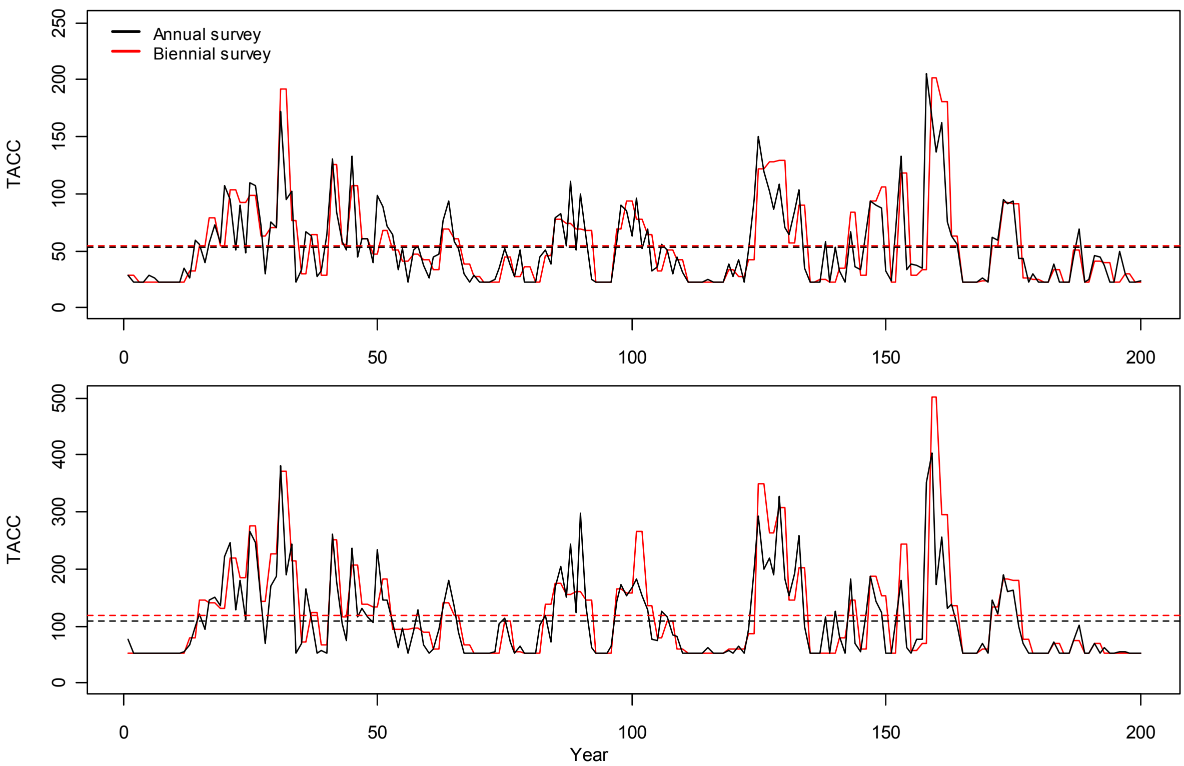

Figure D2: Example time-series of TACCs from survey-rule simulations with annual and biennial surveys. The upper panel shows the decision rule that yields the lowest mean catch (*BaseTACC* = 22 t; *Fmult* = 0.1) and the lower panel shows the decision rule that yields the highest mean catch (*BaseTACC* = 52 t; *Fmult* = 0.3). The same 200 year period is shown in both panels, and the dashed lines show the mean TACC over the 200 years.

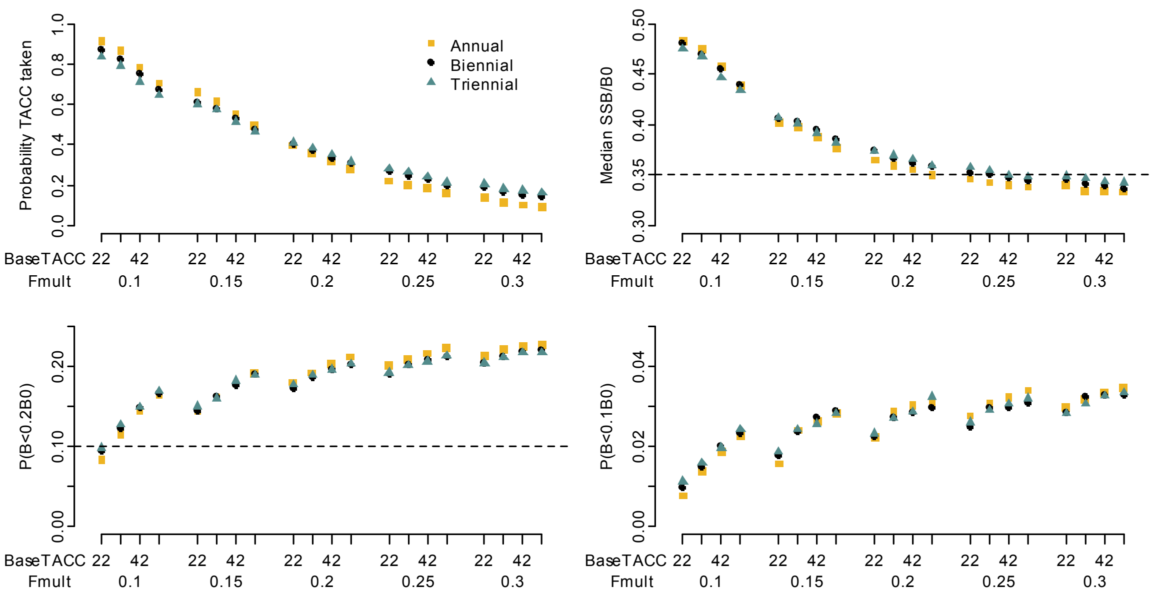

Figure D3: The probability that the TACC is caught, the median ratio of spawning stock biomass to virgin SSB (SSB/B_0), and the probabilities that SSB is less than 20% B_0 and less than 10% B_0 for *Survey* decision rules simulated with annual, biennial and triennial surveys.