Design and evaluation of a revised management decision rule for red rock lobster fisheries (*Jasus edwardsii*) in CRA7 and CRA8.

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We describe the design and evaluation of a new decision rule for the NSS stock of red rock lobsters, *Jasus edwardsii*. The stock comprises fishstocks CRA 7 and CRA 8 in the southern part of New Zealand. A decision rule or simple “management procedure” has been in place since 1997 for this stock. We describe the problems encountered or perceived with the existing rule. A new rule was designed with a different target for CPUE, based on the history of the fishery rather than a rebuild predicted by a stock assessment. The new rule has three parameters that define a large family of candidates for the rule.

Overlying management of this stock is uncertainty about migration between CRA 7 and CRA 8 and about sources of recruitment for each area. Different assumptions about these processes might lead to different management approaches. We evaluated the rules with an operating model that used a variety of assumptions about these processes. Four stock management strategies were defined, ranging from separate management to amalgamation of the two fishstocks. Performance indicators were based on discussions with stakeholders and included indicators that reflected yield, stability of yield, risk to the stock, lobster abundance and diversity of sizes, and the time required to rebuild the stock to the target level.

Based on the results described here, a new NSS decision rule was chosen by the National Rock Lobster Management Group and accepted by the Minister of Fisheries for use for the 2002–04 fishing year.

1. INTRODUCTION

The two southern substocks of the red rock lobster (*Jasus edwardsii*) in New Zealand, CRA 7 (Otago) and CRA 8 (comprising the areas Fiordland, Foveaux Strait and Stewart Island) are considered to form the "southern" or NSS stock of rock lobsters (Booth & Breen 1992). These two Quota Management Areas (QMAs) are considered to form one substock mostly because of irregular migrations of immature animals from CRA 7 to CRA 8 (Street 1973, 1995, T. Kendrick and N. Bentley, unpublished data). CRA 7 tends to have smaller lobsters, and has smaller minimum legal sizes (MLS) than CRA 8. The current size in CRA 7 in the main season equates to 46 mm tail width for both sexes, compared with 54 mm for males and 56 mm for females in CRA 8.

The status of the CRA 7 and CRA 8 fisheries is thought to be poor, with the stock well below levels that could support higher sustainable catches than are taken at present (Breen & Kendrick 1998, Starr & Bentley 2002). Rebuilding the NSS stock to safer and more productive levels is a long-standing management goal.

In the mid 1990s, the National Rock Lobster Management Group (NRLMG), which advises the Minister of Fisheries on rock lobster management issues, began to explore decision rules for management. Decision rules use an agreed indicator or set of indicators from the fishery, and they specify what action will be taken, dependent on the indicator. Under this approach, also called the "management procedure approach" (e.g., Butterworth & Punt 1999), prior agreement is obtained among managers and stakeholders about the indicator data, the decision rule and the period for which the rule will be used. Simulation testing of the rule is used to ensure that it can deliver the desired stock behaviour in the face of known uncertainties.

The advantages of this approach over the conventional pattern of regular or periodic stock assessments, each followed by a decision process, are (loosely based on Geromont et al. 1999):

- uncertainty in all facets of the assessment and management process can be addressed,
- harvest decision rules can be developed that are robust to uncertainty,
- the process leads to explicit definition of management objectives,
- all participants in the fishery can become involved in the choice of rule,
- a long-term view is forced,
- management procedures move away from regular assessments, freeing resources for other research, and
- the process is more understandable to fishers than the conventional approach.

During 1996, NIWA and SeaFIC scientists undertook evaluation of a new decision rule developed specifically for the NSS stock (Starr et al. 1997). This work was in reaction to concerns about the certainty of rebuilding the NSS stock within specific time frames and desires for management action to be explicitly defined and for catch increases to be permitted as well as decreases.

The resulting NSS rule, described below, was adopted in 1997, and operated to cause reductions in Total Allowable Catch (TAC) or Total Allowable Commercial Catch (TACC) in 1999 and again in 2001. This rule was based on standardised catch per unit of effort (CPUE) from the commercial fishery (CRA 7 and CRA 8 combined) as an index of abundance, and acted on the TACs for the QMAs in concert.

A variety of issues, described below, have arisen with respect to the 1997 decision rule and its basis. In its final advice paper of March 2002, the NRLMG undertook to consider refinements of decision rules for this stock by 30 June 2002.

This document describes the technical work carried out to support that undertaking. Management objectives are reviewed, performance indicators are defined, alternative approaches to managing the

NSS stock are evaluated, a new family of rules is described and tested, and a revised NSS decision rule is recommended.

The fishing year runs from 1 April to 31 March of the next year. Throughout this document we adopt the convention of naming a fishing year by its larger portion, *viz* we call the 1996–97 fishing year "1996".

2. MANAGEMENT OBJECTIVES

The NSS stock is estimated to be below B_{MSY} and at a small fraction of virgin biomass (Bentley et al. 2001). A major immediate goal for management of the NSS stock is to increase the stock abundance to a safer and more productive level. At the same time, of course, fishers need to take sufficient catch to remain economically viable. Thus there is a trade-off between the speed of rebuild and catch during the rebuild: longer rebuild times are likely to result from larger catches.

In considering the 1997 rule, a target of 16 years to rebuild was identified from a deterministic projection of CPUE (Starr et al. 1997). In 2002, it was agreed by the NRLMG that 10 years was now the suitable target time for rebuild. This target has a major effect on the trade-off between catch and rebuilding.

2.1 Rebuilding target

Legislation requires that New Zealand fisheries be managed to maintain stocks at or above B_{MSY}, the recruited biomass associated with the maximum sustainable yield (*MSY*). However, B_{MSY} is not defined, and Francis (1999) suggested that B_{MSY} varies among different harvest strategies, which are usually undefined. Older assessments used a deterministic equilibrium approach to calculate B_{MSY} (e.g. Breen & Kendrick (1998), describing the assessment used as the basis for evaluating the 1997 rule). Later assessments (e.g., Bentley et al. 2001) drew attention to the simplistic nature of such an approach.

A workshop on the use of B_{msy} in New Zealand fisheries management held in 2001 suggested that

> "a more pragmatic management approach, consistent with the Purpose of the Act, is to ensure that stocks are managed above, for example, the lowest observed stock size that has been known to give rise to good recruitment" (Stokes et al. 2001).

Following this suggestion, which has also been used to develop reference periods for paua (Breen et al. 2003), we suggested that the NRLMG adopt a target level of CPUE from the history of the fishery. This continues the use of commercial CPUE as an index of abundance.

Specifically, we suggested using the average of standardised CPUE from 1979 through 1981. These are the first three years for which reliable CPUE data are available. The CPUE from this period was higher than at any subsequent time to the present. CPUE, and its associated biomass, then declined rapidly to about 1 kg/potlift by the mid 1980s in CRA 8. However, this lower biomass level, which was much less than the proposed target level, supported a fishery in the CRA 8 for the next 15 years. That fishery had limited entry but no harvest ceiling until 1989. Catches during that period were higher than the current TAC. Therefore, a target CPUE which is nearly twice the recent level should serve as a reasonable and achievable reference biomass target.

Adoption of this target level would require a substantial increase in CPUE from the current level. In CRA 8 this increase would be from near 1.3 kg per potlift to 1.9 kg per potlift. The industry and NRLMG agree that higher CPUE and associated higher biomass are desirable. Higher CPUE implies higher catch rates and lower catching costs, enhanced safety for the fishery, and greater choice of sizes available when the market has differential prices based on size. Thus the suggested new target is realistic, given the history of the fishery, and is consistent with the aims of both the Ministry and industry.

2.2 Stakeholder input on objectives

In 2000, the authors held a workshop for stakeholders and the NRLMG to solicit management objectives (Bentley et al 2003). The NRLMG agreed that six major objectives arising from that workshop should be considered during this work. These objectives are shown in Table 1. The NRLMG agreed that social and economic factors should be considered in the choice of a management strategy. Although the management objectives used are not explicitly social or economically based, they do include stakeholder concerns regarding the viability of the fishery (Table 1).

Table 1: Management objectives and their associated performance indicators to be considered evaluating decision rule candidates.

Name	Objective	Performance indicators
Yield	Maximise catch	Mean annual catch (t) Probability of falling below current TACC during a simulation (%Catch low)
Abundance	Maintain high abundance to reap economic, biological, and social benefits of high catch rates	Mean of CPUE (kg per potlift)
Stability	Minimise frequency of quota adjustments – a maximum of 3 to 5 years is preferred	Frequency of TAC adjustments Average annual variation in TACC (% AAV)
Safety	Minimise risk of low biomass levels	Probability of CPUE falling below the 1997 level during a simulation (%CPUE low)
Diversity	Maintain a wide size range of lobsters – fishers are able to respond to changes in market demand	The proportion of lobsters in the catch that weigh 1kg or more (%Large)
Rebuild	Maximise rate of rebuild	Mean annual percentage increase in CPUE Times to rebuild (yrs)

There are numerous trade-offs among these objectives, in particular between abundance and yield, and between yield and speed of rebuild. These will be illustrated below. Thus the choice of specific rule is very much a poorly defined optimisation problem. We considered developing a utility function for comparing rules, but shied away from this approach because of its requirement to weight the objectives. Instead, we obtained exact specifications from the NRLMG on three objectives: safety, stability and rebuild time. These were:

- the rule must rebuild the fishery to the target CPUE within 14 years with a high probability;
- it must result in CPUE higher than the starting CPUE in at least 17 of the next 25 years with a high probability; and
- it must result in an average annual variation in catch of less than 10% with a high probability.

Candidate rules were ranked in their probability of meeting all three specifications, as will be described below, and the highest few were then compared in terms of mean catch and the distribution of time to rebuild.

3. ALTERNATIVE STOCK MANAGEMENT STRATEGIES

A major uncertainty for management of CRA 7 and CRA 8 is the extent to which CRA 7 and CRA 8 could or should be managed separately or together. In turn, this question hinges on:

- the extent to which lobsters move from CRA 7 to CRA 8, and from Stewart Island to Fiordland within CRA 8,
- the extent to which lobsters from each stock contribute to the recruitment of each stock (several alternative possibilities exist), and
- the extent to which growth and mortality rates differ between stocks and sub-stocks.

Migrations are known to occur from CRA 7 to the Stewart Island area (Street 1973, 1995) from the Stewart Island area to Fiordland and north within Fiordland (McKoy 1983, 1985, Annala & Bycroft 1993, T. Kendrick & N. Bentley, unpublished data). The proportion of lobsters that migrate and the consistency of the migrations are unknown.

Stock-recruit relations are unknown. Fiordland appears to have the greatest biomass of mature lobsters, but there is no information on the extent to which egg production from this area contributes to settlement in Otago, Stewart Island and indeed Fiordland. There is even a possibility that some recruitment to the NSS originates in Tasmania, because the populations are not genetically isolated (Ovenden et al. 1992).

Growth and mortality rates are not well studied; differences among CRA 7 and the two major regions of CRA 8 may well exist.

Optimal management of the NSS stock depends largely on the dynamics of lobster movement and recruitment. For instance, if most CRA 7 lobsters migrate to CRA 8, and recruitment to CRA 7 depends on CRA 8 egg production, amalgamated management with a single size limit might be favoured. Alternatively, if most recruitment came from Australia and no movements occurred, then separate management might be favoured.

For this study we originally defined and considered four alternative harvest strategies:

- **Current**, in which a single catch-setting rule is based on the combined CRA 7 and CRA 8 CPUE and is applied simultaneously to both stocks,
- **Joint**, in which a single (but different from current) catch-setting rule is based on the combined CRA 7 and CRA 8 CPUE and is applied simultaneously to both stocks,
- **Separate (A)**, in which separate catch-setting rules are based on CPUE for CRA 8 and in-season data for CRA 7, and using a rebuild trajectory for CRA 8 only; and
- **Amalgamated**, in which CRA 7 and CRA 8 are managed together as a single QMA with a single TAC, single MLS, and a single decision rule single rule based on CRA 8 CPUE and a rebuilding trajectory.

The Current strategy describes the approach in place at the time of the study, using the 1997 decision rule.

The Joint strategy is similar is similar to the Current, differing by having a different rebuilding target trajectory and final target value.

The Separate(A) strategy comprises different strategies for each of CRA 7 and CRA 8. The strategy defined for CRA 8 was a rebuilding decision rule, based only on the CRA 8 CPUE data. The strategy for CRA 7 was a constant-exploitation rate rule.

The rationale for the Amalgamated strategy was that, depending on the dynamics, there may be little reason to have separate quotas and minimum legal size limits in the two areas. Under this strategy, both areas would have the same MLS, and quota could be caught in either area.

The NRLMG discussed early evaluations comparing the outcomes of these four strategies (results presented in section 6) and considered practical realities. Whatever the merits of the alternatives, it seemed likely that neither Separate(A) nor Amalgamated could be implemented in 2002. It was agreed to proceed with a hybrid based on the "Separate" harvest strategy:

- **Separate(B)**, in which a single catch-setting rule is based on CPUE for CRA 8 and uses a rebuild trajectory for CRA 8 only; but under which in the short term catch changes are also applied to CRA 7.

This rule allows CRA 7 the option of continuing to be governed by the CRA 8 rule or developing an alternative rule specific to CRA 7. Selection of final candidates for a decision rule was based only on evaluations of the Separate(B) harvest strategy.

4. DECISION RULE DESIGN

In this section we describe the 1997 decision rule applied to both CRA 7 and CRA 8, identify and discuss problems encountered with this rule, and describe a family of rules from which the revised rule was chosen.

4.1 The 1997 NSS decision rule

The 1997 decision rule was described by Starr et al. (1997). It compares observed CPUE with a target trajectory from the 1996 stock assessment for CRA 7 and CRA 8 combined. A deterministic forward simulation was made by allowing the population model to run forward under constant recruitment (the average recruitment from the assessment) with the estimated 1995 levels of annual removals (1006 t) beginning from the model's estimated 1995 biomass. Biomass reached the deterministic estimate of B_{msy} in 12 years. The target trajectory is compared with observed CPUE (in 2001) in Figure 1.

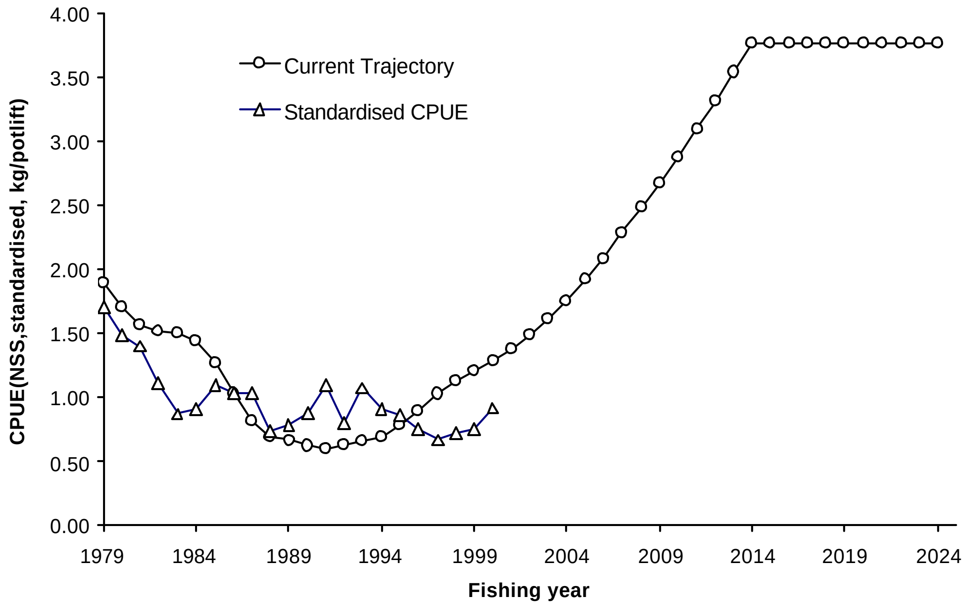

Figure 1: Current NSS CPUE target trajectory and the actual standardised CPUE through 2000.

For each year indexed by t, the rule calculates the position of observed CPUE relative to the target trajectory of CPUE:

$$A_t = I_t^{obs} / I_t^{pred} - 1$$

where A_t is the CPUE comparison for year t, I_t^{pred} is the expected CPUE from the target trajectory, and I_t^{obs} is the CPUE observed in year t. These are then averaged for three years to obtain a mean difference:

$$\overline{A}_t = \frac{1}{3} \sum_{d=t-2}^{d=t} A_d$$

Under this rule, the catch is increased by 20% if $\overline{A}_t$ exceeds 1.25, and decreases by 20% if $\overline{A}_t$ is less than 0.75. A "latent year" provision allows catch to be changed only if catch was not changed in the previous year, preventing further change in the year following a change. This provision allows catch adjustments some time to take effect in an effort to stop the rule from "over-correcting".

Because the catch rate data enter the system with a lag, and because some lead time is required for proposed change to be discussed and consulted upon, catch rate data from year t are analysed and the decision rule evaluated in year t+1, and the decision is applied to the beginning of year t+2. This is effectively a 1-year lag. For some years, an "assessment year" was defined from 1 October through 30 September, in an attempt to capture the most recent CPUE information for both decision rules and the assessment, but this approach was not successful and the assessment year reverted to the fishing year.

The current NSS rule was agreed to by the NRLMG and the Minister in 1996 and first evaluated in 1997. The rule operated to cause a TACC reduction for CRA 7 and CRA 8 in 1999 and again in 2001.

4.2 Problems with the 1997 decision rule

Several concerns have been identified with the 1997 decision rule:

- the target trajectory is becoming dated, being based on an assessment made in 1996;
- the final target value may not be realistic (this is discussed further below);
- the final target is based on a simplistic way of calculating B_{msy} (discussed above);
- observed CPUE has increased in the NSS and parallels the target trajectory, but is so far beneath the target trajectory that many further catch cuts now seem inevitable;
- the rule is capable of cutting the catch even when CPUE is increasing strongly;
- the rule is based on the combination of data from CRA 7 and CRA 8, which may not be appropriate; and
- fishers lost confidence in the rule: CRA 8 fishers complained that CRA 7 had always had low CPUE, depressing the combined CPUE, while CRA 7 fishers complained that the 1997 rule would deny them access to any good recruitment that arrived in CRA 7.

The final target for CPUE under the 1997 rule was 3.61 kg per potlift, estimated from the 1996 assessment model biomass and an estimated relation between biomass and CPUE. Data used in the assessment, apart from catch estimates, were all from the late 1970s through the 1990s, when CPUE was always much less than the B_{msy} target. Thus, the existing CPUE target may not be realistic because

- the target is an extrapolation of the recent relation between biomass and CPUE, which relation may change as biomass increases;
- in particular, pot saturation may cause CPUE to reach an asymptotic value as biomass increases; and
- in any case, such high CPUEs were never documented in this fishery, and other NZ lobster fisheries have not had such high average values.

4.3 A new decision rule for rebuilding

The authors, in consultation with the NRLMG, agreed to develop a new decision rule retaining some features of the 1997 rule:

- the new rule is based solely on standardised CPUE observations compared with a target trajectory;
- it has a single target CPUE value at which the fishery is considered to be rebuilt;
- it has a latent year, as in the current rule: if the rule changes catch in year *t*, there can be no change to catch in year *t*+1; and
- the rule has a one-year lag in data: CPUE from year *t* are analysed in year *t*+1 and used by the rule to decide the catch for the start of year *t*+2.

The NRLMG viewed preliminary results from work that explored reducing the lag between data and decision, but agreed to maintain the current situation with respect to lag because reducing the lag did little to improve rule performance. These results are shown below.

The new rule differs from the old, first, in that the target CPUE is based on the 1979–81 CPUE. For a CRA 8 trajectory, used in the evaluations of rules under the Separate and Amalgamated strategies, the final target is 1.9 kg per potlift (Figure 2). The target trajectory was made linear between the 1997 CPUE (0.94 kg per potlift, the lowest recorded) and the target value for 2011.

This approach is consistent with the goal of rebuilding the fishery in 10 years from a starting point in 2001, and gives earlier target values so that the rule can be evaluated in the first year after implementation. This last point was necessary for a rule to be proposed in 2002: it was necessary that, in theory, catch changes could be triggered for 2003. Without this requirement, the rule could be proposed on the grounds that industry were simply supporting a rule that did not lead to any TAC reduction.

For the Joint strategies, the combined CRA 7–CRA 8 target was 1.53 kg per potlift, and the trajectory was calculated in the same way as just described for CRA 8.

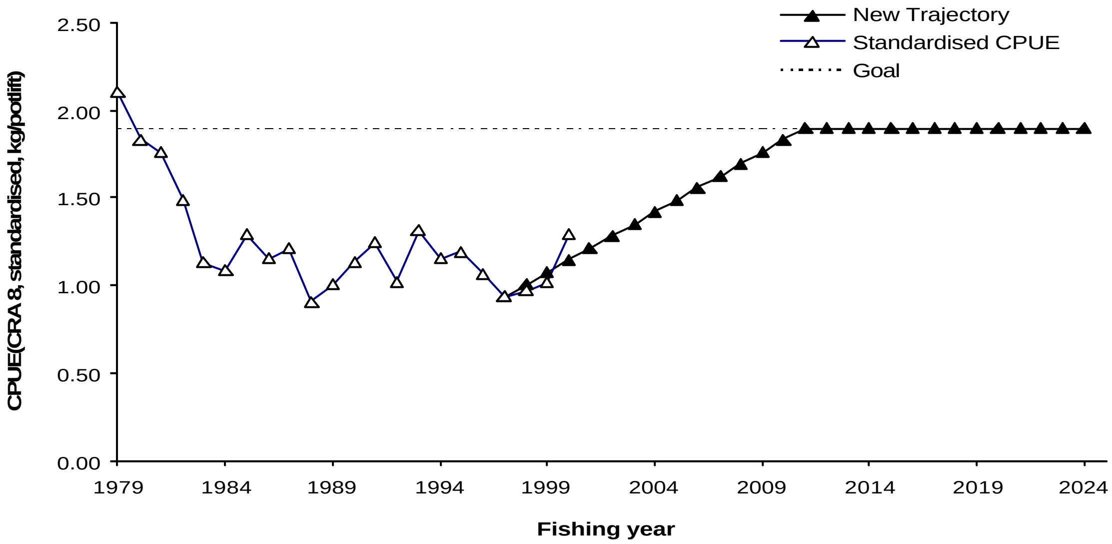

Figure 2: Proposed CRA 8 CPUE target trajectory (closed triangles) and the actual standardised CPUE (open triangles) through 2000.

Second, the new rule examines both the position of CPUE (is it higher or lower than the target?) and the gradient (is observed CPUE increasing or decreasing, and is the target CPUE trajectory increasing or flat?).

These changes make the rule more complicated than the 1997 rule, but should provide better performance. The 1997 rule can decrease catch even when CPUE is increasing strongly, or vice versa. By looking at the direction of change, the new rule should reduce the onset of unstable oscillation possible in the current rule.

The new rule acts by calculating a multiplier that determines the new catch from the existing catch:

$$TAC_{t+2} = Z_t \, TAC_{t+1}$$

The Z_t is calculated from observed and target values for CPUE and from three parameters of the rule:

- ***N***, the number of years used for averaging CPUE in the rule;
- ***W***, relative weight given to the distance between observed and target CPUE, relative to the difference between target and observed gradients; and
- ***S***, a scaling or sensitivity parameter used to determine the rule's response.

These three parameters thus define a large family of candidate decision rules. The rule proposed by the NRLMG in June 2002 is one specific member of this family, selected after the extensive testing described below.

In this family of rules, the difference between target and observed CPUE is calculated in a "status indicator" for each year of data:

$$A_t^s = I_t^{obs} / I_t^{pred} - 1$$

Similarly, the difference between the target and observed gradient is calculated in a "gradient indicator:

$$A_t^g = \left(\left(I_t^{obs} - I_{t-1}^{obs}\right) / I_{t-1}^{obs}\right) - \left(\left(I_t^{pred} - I_{t-1}^{pred}\right) / I_{t-1}^{pred}\right)$$

Each is averaged for N years:

$$\overline{A}_t^s = \frac{1}{N} \sum_{d=t-N+1}^{d=t} A_d^s$$

and similarly for A_t^g to obtain $\overline{A}_t^g$. The mean gradient and status indicators are combined, using the relative weight W:

$$A_t^* = W\overline{A}_t^s + (1-W)\overline{A}_t^g$$

Now the combined mean indicator is used with the scalar S to determine a response:

$$R_t = SA_t^*$$

Then this response is used to determine the multiplier Z_t , taking into account the sign of R_t and limiting the magnitude with minimum and maximum thresholds. The minimum threshold is 0.05, and the maximum is 0.25.

$Z_t = 1$	for -0.05 = (R_t) = 0.05
$Z_t = 1 + R_t$	for -0.25 = (R_t) < -0.05 and
	for 0.05 < (R_t) = 0.25
$Z_t = 0.75$	for (R_t) < -0.25
$Z_t = 1.25$	for (R_t) > 0.25

As in the 1997 rule, a “latent year” is specified, prohibiting changes to TAC in two consecutive years.

4.4 An alternative type of decision rule for a constant exploitation rate

The CRA 7 fishery is unusual amongst New Zealand rock lobster fisheries because catches are dominated by small animals and large or mature animals are scarce. This could arise for several reasons, including low growth rates, high exploitation, high natural mortality, or emigration of larger lobsters.

There is substantial anecdotal evidence that lobster do migrate out of CRA 7. Fishers report southward moving ‘runs’ of immature lobsters (Street 1973, 1995) and long distance movements by lobsters in the area are described in a review of historic tagging data (Booth 1997). If lobsters do migrate out of the area, then management of CRA 7 that is based on the assumption that biomass will accrue to the stock is likely to be inappropriate. An alternative would be to manage the stock under a constant exploitation rate (CER) strategy. Under this strategy, the fishery would harvest in proportion to the available biomass and would leave a proportion to migrate to other areas.

Over the last 11 years, the CRA 7 fishery has had a pattern of catch and CPUE similar to what it would have under a CER strategy. In only two years, 1991 and 1993, did TACC limit the commercial catch (Figure 3). In the last seven years, catches have been consistently below the TACC and have showed a similar trend to CPUE. The high correlation between CPUE and the commercial catch for the period 1993 through 2000 reflects roughly constant effort.

4.4.1 Estimating vulnerable biomass

Under a CER strategy, the TAC would be set each year based on a target exploitation rate ($\overline{U}$) and an estimate of vulnerable biomass in that year (B_t):

$$TAC_t = B_t \overline{U}$$

Thus to implement a CER strategy it is necessary to (a) decide what the target exploitation rate should be, and (b) estimate the biomass in each year. The mean annual exploitation rate over the last 11 years could be used as a target:

$$\overline{U} = \frac{\sum_{t=1990}^{2000} C_t / B_t}{11}$$

To estimate vulnerable biomass an assessment would be necessary. However, if CRA 7 is indeed based upon a transient population there is likely to be little information from which an assessment model could estimate the absolute vulnerable biomass; without estimates of the vulnerable biomass, it is difficult to estimate what exploitation rates have been.

An alternative is to use CPUE as an index of vulnerable biomass and seek to maintain the current exploitation rate. That is, biomass is replaced by CPUE and a scalar derived based on the recent annual ratios between catch and CPUE:

$$\overline{S} = \frac{\sum_{t=1990}^{2000} C_t / CPUE_t}{11}$$

The TAC in each year could then be set by using the scaler with the predicted CPUE:

$$TAC_t = CPUE_t \overline{S}$$

This procedure for setting TAC would maintain a constant exploitation rate consistent with that in the last 11 years without the need to estimate vulnerable biomass in each year. The scalar calculated is 229.3 t/(kg/potlift).

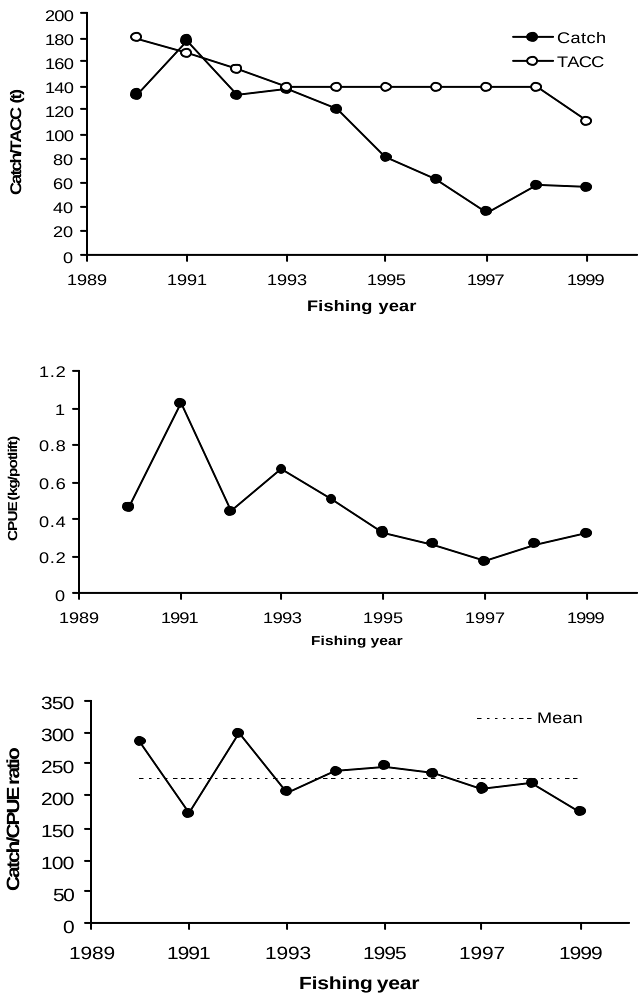

Figure 3: Relation between commercial catch and standardised catch per unit effort in CRA 7, 1990 through 2000.

4.4.2 Predicting CPUE

CPUE is a relative index of vulnerable biomass, so there are fewer difficulties in predicting CPUE for a year than in predicting absolute vulnerable biomass. We examined two sets of data for predicting CPUE for a year: indices of pre-recruit abundance derived from catch sampling in the previous year, and the CPUE from the first weeks of the season.

4.4.2.1 Using indices of pre-recruit abundance

4.4.2.1.1 Methods

Extracts were made from the catch sampling and voluntary logbook databases for all sampled catch information by length, sex and maturity from statistical areas 920 and 921. The number of potlifts sampled was also extracted. This extract was summarised in 2-mm tail width length bins in three sex categories (males, immature females and mature females) by fishing year for all vessels. The extract was then collapsed by fishing year across the three sex categories into three size limit categories of rock lobster (Table 2).

For each size category of undersized lobster, two measures of relative abundance were calculated. One measure was the numbers of undersized rock lobster per sampled potlift; the other was the ratio of the number of undersized lobster to the number of legal sized lobster. These measures of relative abundance were regressed against the estimate of the annual standardised CPUE for the following fishing year.

Table 2: Definitions of size limit categories for the analysis of pre-recruits in CRA7.

Size limit category	Definition
Under size limit	Under 46 mm tail width for males and females
Pre-recruit	Between 42 and 45.9 mm for males and females
Over size limit	46 mm and above for males and females

4.4.2.1.2 Results

The relation between abundance (numbers per potlift, Figure 4) of undersized or pre-recruit lobster appears to be stronger than the ratio of undersized lobsters to lobster above the size limit. However, the explanatory power of these predictive relationships is low (Table 3). The regressions appear to be highly influenced by the 1990 data point (high numbers of pre-recruits in 1990 and a high CPUE in 1991) and the correlation coefficients would be less if this were excluded.

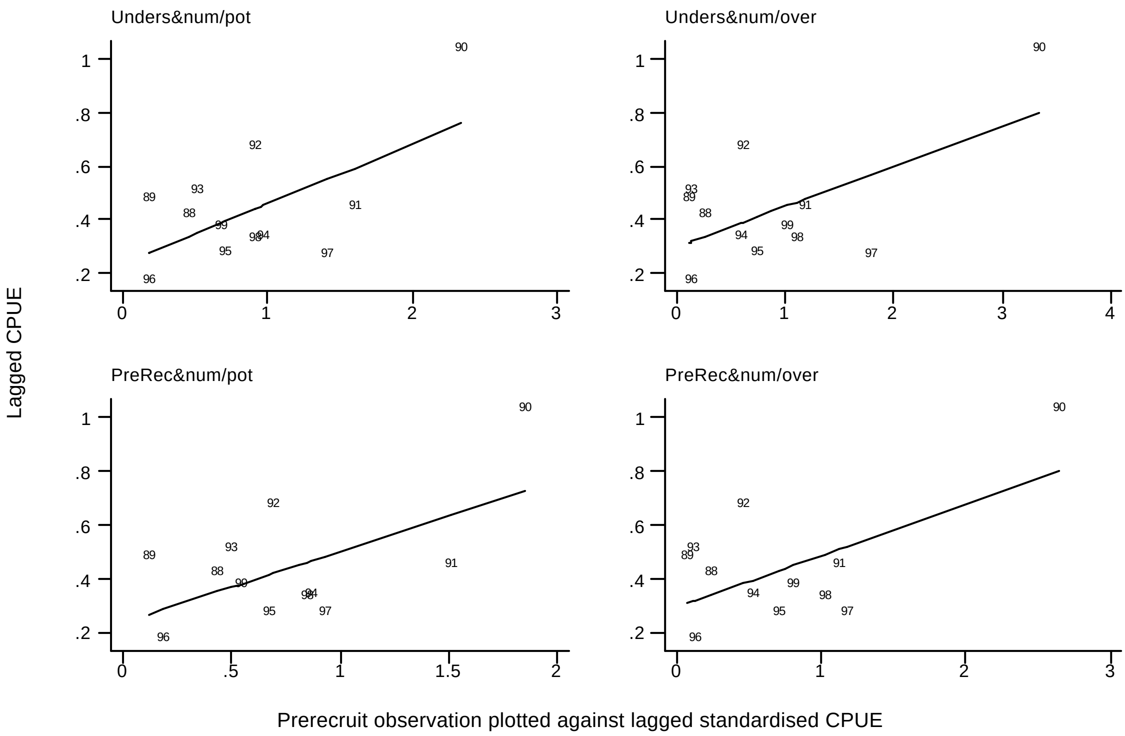

Figure 4: The relation of pre-recruit observations against standardised CPUE in the following year. Two pre-recruit categories are shown: a) the sum of numbers below the size limit (=Unders) and b) total numbers up to 4 mm tail width below the size limit (=PreRec). These two categories are expressed as numbers per potlift and as number of pre-recruits divided by number over the size limit.

Table 3: Parameter estimates and coefficients of determination (R^2) for regressions between various indices of pre-recruit abundance and commercial CPUE in the following year.

		Slope		Intercept		
Abundance measure	Data type	Estimate	SE	Estimate	SE	R^2
Numbers per potlift	Under SL	0.224	0.091	0.234	0.098	0.379
	Pre-recruits	0.265	0.116	0.234	0.104	0.345
ratio of pre-recruits to recruits	Under SL	0.149	0.062	0.300	0.079	0.367
	Pre-recruits	0.194	0.079	0.290	0.081	0.374

Stakeholders in CRA 7 expressed concern that catch sampling data from statistical area 921 may weaken the relationship between pre-recruit abundance and subsequent CPUE because the fishery in that area is thought to be based mainly on migrating lobsters (R. Brady, NZ Rock Lobster Industry Council, pers. comm.). Thus, we repeated the analysis using catch sampling data only from area 920 (Figure 5). Although there was a slight increase in the coefficient of determination, the relationship was still poor (Table 4) and again influenced by one data point (1990).

Table 4: Parameter estimates and coefficients of determination (R^2) for regressions between various indices of pre-recruit abundance from statistical area 920 only and commercial catch per unit effort in the following year.

		Slope		Intercept		
Abundance measure	Data type	Estimate	SE	Estimate	SE	R^2
Numbers per potlift	Under SL	0.252	0.081	0.238	0.082	0.461
	Pre-recruits	0.273	0.087	0.251	0.104	0.366
Ratio of pre-recruits to recruits	Under SL	0.291	0.077	0.162	0.062	0.401
	Pre-recruits	0.292	0.079	0.197	0.079	0.383

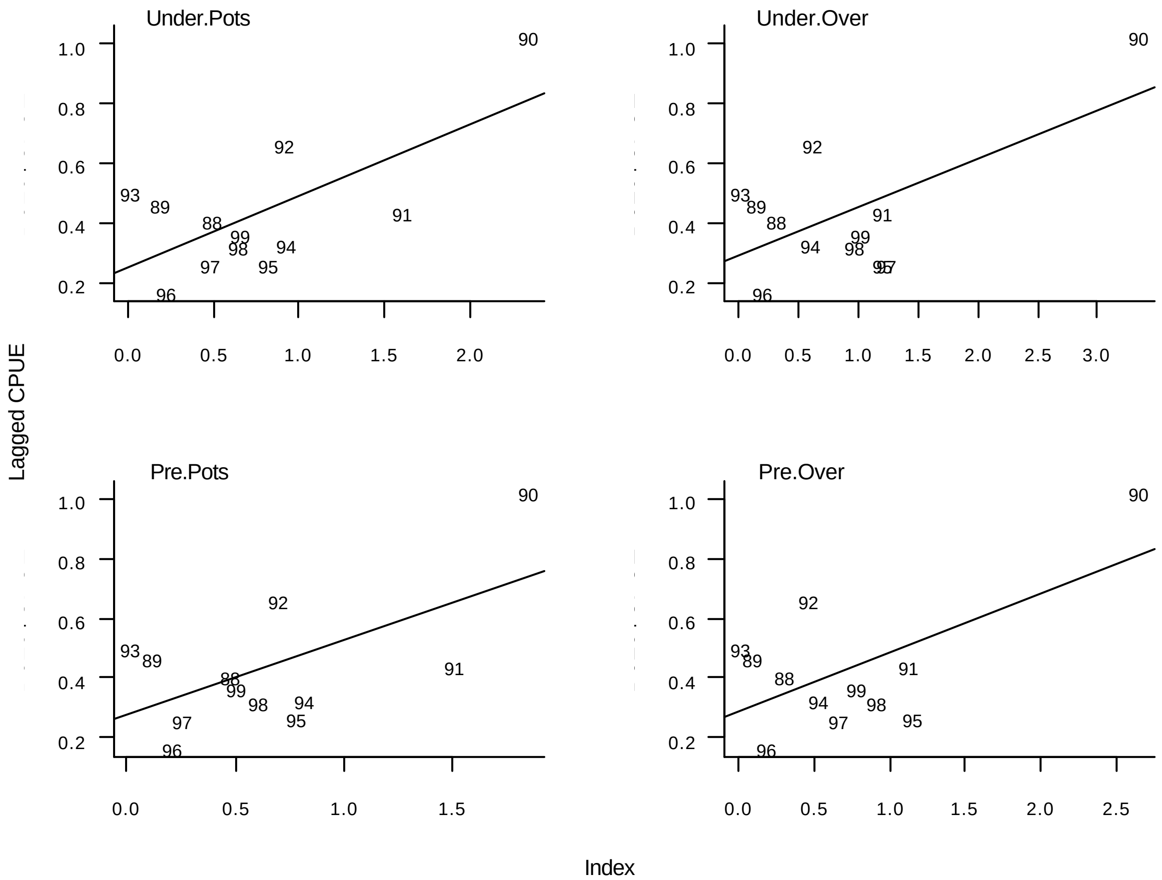

Figure 5: Plot of the relation of pre-recruit observations from statistical area 920 only, against standardised CPUE in the following year. Two pre-recruit categories are shown: a) the sum of numbers below the size limit (=Unders) and b) total numbers up to 4 mm tail width below the size limit (=PreRec). These two categories are expressed as numbers per potlift and as number of pre-recruits divided by number over the size limit.

4.4.2.2 Using start-of-season catch rates

4.4.2.2.1 Methods

An extract was made from the CRACE (N. Bentley, P. Starr and T. Kendrick, unpublished data) CELR database for all catches and potlifts from statistical areas 920 and 921 from 1 October 1989 through 31 March 2001. This extract was summed over each day for all vessels. The catch data in this extract were adjusted to reflect the landings data for the same form.

A preliminary analysis of the data showed that, although there were isolated landings in the early part of the year, the first landings of importance started on 21 June in each year. Accordingly, this date was chosen as the first day of the first week and nine seven-day weeks were identified from 21 June to 22 August in each year. The catch data for the remainder of the year were placed in an accumulated "plus" week.

For each week, the total catch and effort were calculated, including the catch and effort from all preceding weeks, providing the best estimate of the abundance for each year up to and including that week. This estimate was compared with the total landed catch as reported to the QMR, and was regressed against an estimate of the annual standardised CPUE for CRA7 in that year.

4.4.2.2.2 Results

There is a strong relationship between total annual reported catch from CRA7 and the early estimates of CPUE (Figure 6). When annual standardised CPUE is regressed against the cumulative estimates of CPUE, the results show a high level of correlation (Table 5, Figure 7). Residual patterns are moderately well dispersed with deviations on the order of 0.05 to 0.1 kg per potlift from the predicted values (Figure 8). This level of predictive power in the first week of data results from evaluating less than 10% of the total annual catch in most years (Figure 6).

Table 5: Regression parameters for each fitted week plotted in Figure 7. Each sigma is the standard deviation of the parameter estimate for the slope and the intercept respectively.

Week	Slope	Sigma	Intercept	Sigma	R^2
1	0.702	0.088	0.121	0.048	0.877
2	0.868	0.102	0.077	0.049	0.890
3	0.871	0.176	0.064	0.085	0.731
4	0.941	0.190	0.049	0.088	0.732
5	1.050	0.188	0.016	0.084	0.777
6	1.094	0.187	0.005	0.082	0.791
7	1.174	0.190	-0.027	0.082	0.809
8	1.200	0.190	-0.045	0.083	0.816
9	1.221	0.167	-0.055	0.073	0.856

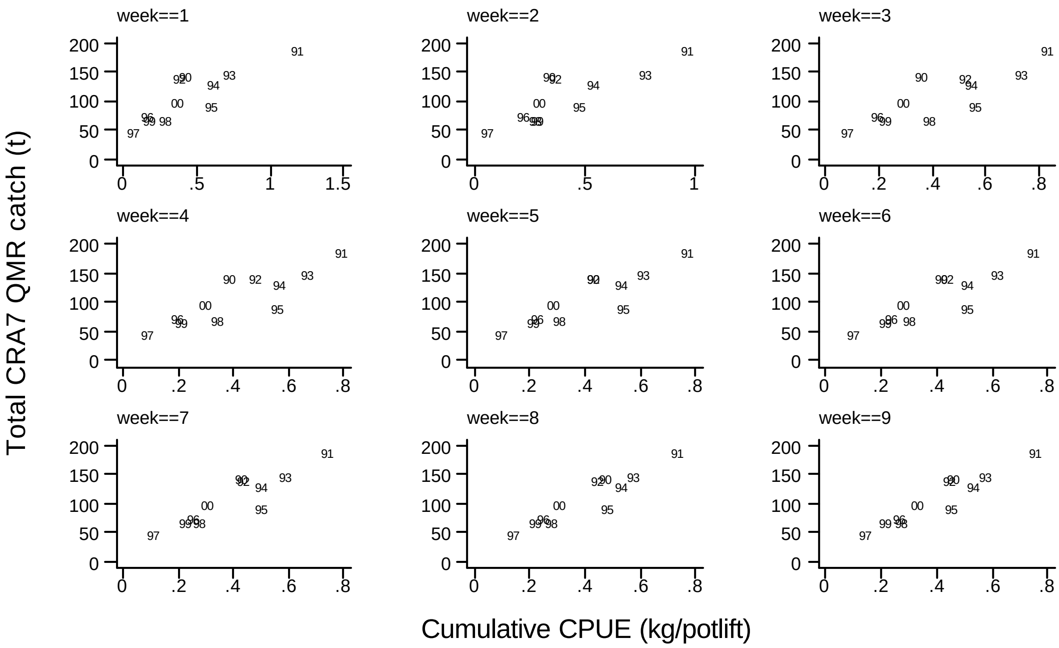

Figure 6: Cumulative weekly CPUE (kg per potlift) plotted against total annual QMR catch (t) for CRA 7 for all fishing years from 1990 through 2000. Week 1 begins at 21 June in each year and the year of the estimated CPUE is used as a plotting symbol.

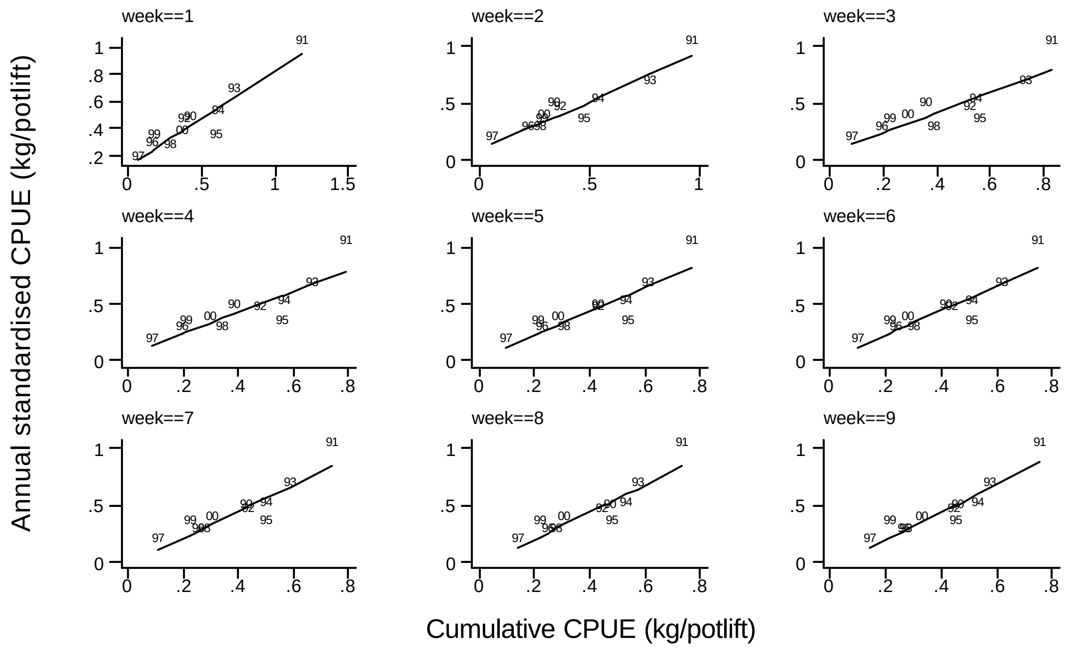

Figure 7: Cumulative weekly CPUE (kg per potlift) plotted against annual standardised CPUE (kg per potlift) from CRA 7 for all fishing years from 1990 through 2000. Week 1 begins at 21 June in each year and a least squares regression has been fitted to each week of data. The year of the estimated CPUE is used as a plotting symbol.

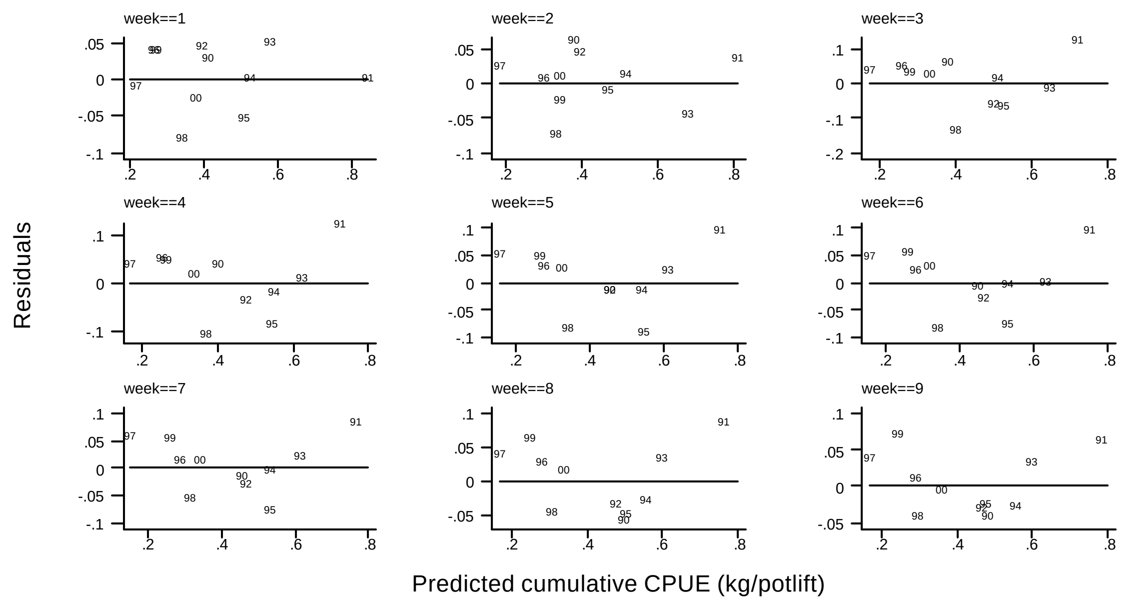

Figure 8: Residuals by week plotted against predicted cumulative weekly CPUE (kg/potlift) for CRA7 for all fishing years from 1990 through 2000. Week 1 begins at 21 June in each year and a least squares regression has been fitted to each week of data. The year of the estimated CPUE is used as a plotting symbol.

Table 6: Cumulative catch (% of total annual catch) by fishing year for the first 9 weeks of the CRA7 fishery. Also provided is the total catch (t) in the annual dataset from 21 June to the end of the fishing year and the total reported QMR catch (t).

Fishing	Week from 21 June									Total	QMR
year	1	2	3	4	5	6	7	8	9	catch	catch
90–91	6	8	12	18	27	32	37	47	50	124.8	133.4
91–92	16	25	34	43	49	57	64	69	75	169.4	177.7
92–93	5	8	16	22	25	30	34	40	45	138.0	131.6
93–94	12	26	36	41	47	57	60	65	72	133.1	138.1
94–95	7	11	18	28	34	36	42	52	59	126.8	120.3
95–96	8	14	25	34	40	48	52	58	61	110.7	81.3
96–97	3	8	10	14	20	26	34	38	46	57.3	62.9
97–98	3	4	8	13	17	22	29	40	44	16.7	36.0
98–99	5	10	26	33	35	44	52	60	65	28.9	58.6
99–00	3	11	14	17	23	24	31	35	38	44.9	56.5
00–01	5	10	15	22	26	30	40	45	53	82.7	87.2

4.4.3 Discussion

It would be useful to be able to predict CPUE in the CRA 7 fishery well in advance. However, the more in advance a prediction is made, the less accurate it is likely to be. A trade-off must be made between forewarning and accuracy. The analyses presented here suggest that, given the data currently available, it would preferable to use an in-season predictor of annual CPUE. One-year-ahead predictions derived from catch sampling data do not appear to provide enough accuracy to implement a constant exploitation rate strategy, but early-season CPUE may be accurate enough.

5. OPERATING MODEL

To evaluate the family of candidate decision rules under the four management strategies identified in Section 3, an operating model was used:

- to simulate a spatially structured NSS stock,
- to simulate catches from the stock and their effect on subsequent abundance, and
- to simulate operation of a decision rule each year to determine the next year's catches in CRA 7 and CRA 8.

5.1 Structure of the model

The structure of the size- and sex-based operating model was based on the assessment model used for the 2001 stock assessment (Breen et al. 2002). The dynamics are described in the assessment report; only changes made to develop the operating model are reported here. There is no provision for parameter estimation: see below for details of parameter choice.

The model used a starting population in equilibrium with the estimated 1999 exploitation rate (Bentley et al. 2001). The most recent 10 recruitment deviations from that assessment were used to generate the starting population and for projections.

5.2 Spatial structure

Three separate lobster populations and fisheries were simulated, representing Otago (statistical areas 920 and 921), Stewart Island and Foveaux Strait (areas 922–924), and Fiordland (areas 926–928). We modelled Stewart Island and Foveaux Strait separately from Fiordland because the two areas have possibly different population dynamics and relationships with Otago. The model incorporated the MLS, selectivity- and maturity-at size characteristics of each of the three areas.

5.3 Egg production

Total egg production in each area during each year ($E_{t,a}$) was modelled using a fecundity-at-size relation and numbers of mature females.

$$E_{t,a} = \sum_s N_{t,a,s} a S_s^{\ b}$$

where *s* indexes size. The same values of a and *b* were used for all three areas.

5.4 Stock-recruitment relations

For each run in the sets of evaluations, the model randomly chose, with equal frequency, between two alternative schemes. In the first scheme, larval production is made proportional to egg production in each area, and larvae are distributed among areas as shown in Table 7. Because of the predominately westward flow of currents in the area, we assume that all Otago eggs produce Otago larvae, and that Fiordland eggs produce larvae in all three areas. The density-dependent stock-recruit function is applied before larvae recruit to the model.

Table 7: Matrix of the dispersion of larvae in the first scheme. The rows represent sources of larvae (eggs), columns represent the destination of larvae.

		Destination		
		Otago	Stewart I.	Fiordland
Source	Otago	1.0	0.0	0.0
	Stewart I.	0.5	0.5	0.0
	Fiordland	0.3	0.3	0.4

In the second scheme, the model assumes that a source of larvae that is unrelated to egg production has a mean equal to the virgin recruitment level, and that recruitment is distributed 20% to Otago, 30% to Stewart Island and 50% to Fiordland.

5.5 Settlement

Density-dependent post-settlement survival was modelled using a Beverton-Holt stock recruitment relationship parameterised using virgin recruitment, R_0 and steepness z. Stochastic variation in settlement was simulated by applying a stochastic multiplier to the total numbers of larvae transported to each area. A multiplier of 1 implies the mean rate of larval survival. Multipliers were generated independently for each of the three areas from a lognormal distribution with a mean of 1 and a standard deviation of $s^{\ s}$:

$$N^s_{t,0} = \frac{S_t}{a + b\ S_t} R_t$$

$$a = S_0 \frac{1-z}{4z\ R_0}$$

$$b = \frac{5z-1}{4zR_0}$$

where S_0 is the mean egg production from the virgin stock.

5.6 Size of migration

Lobsters are thought to migrate just before the onset of maturity. Thus, we modelled the probability of individual lobsters moving, H_s, as a logistic function with a size at 50% probability d mm tail width less than the size of maturity, m_{50}:

$$H_s = \frac{1}{1+\exp\left[\frac{-\ln(19)\left(\bar{S}_S - m_{50} - d\right)}{w}\right]}$$

where $\bar{S}_S$ is the mean size of animals in the *S*th size group. The steepness of this function is determined by w and we assume this to be the same as the steepness of the maturity curve. The size of maturity for males is unknown and was assumed to be the same size as for females.

5.7 Migration destination

The number of lobsters eligible to migrate is determined from the size distribution and migration ogive described above. The proportions that migrate, and their destinations, are determined by three parameters, *a, b* and *c* (Table 8).

Table 8: Matrix of migration. The rows represent sources of migrants, columns represent the destination of migrants. Values or expressions in the cells represent the proportion of migrants from that source which migrate to that destination.

		Destination		
		Otago	Stewart I.	Fiordland
Source	Otago	1-*a*-*b*	*a*	*b*
	Stewart I.	0	1-c	c
	Fiordland	0	0	1

5.8 Other differences from stock assessment model

5.8.1 Relative vulnerabilities of each sex category

The model used here has an annual time step, so the relative vulnerabilities for each sex category during each season had to be combined. We did this using estimates of the proportion of catch taken during each season (autumn-winter, AW, and spring-summer, SS) in CRA 8. Based on the data compiled for the 2000 assessment, between 1990 and 2000 the average proportion of annual legal catch taken in the autumn-winter period (1 April to 31 September) was 0.40 for CRA 8. The relative vulnerability of each sex, v^s, was a weighted combination of the seasonal estimates, r^s_{AW} and r^s_{SS}, from the 2000 assessment model:

$$v^s = 0.4r^s_{AW} + 0.6r^s_{ss}$$

5.8.2 Legality of mature females

We assumed that all mature females were ovigerous (berried) during the AW. Thus, the annual proportion of mature females that are legal is 0.6.

5.8.3 Size limit in CRA 7

For CRA 7 the length at maximum selectivity was assumed to be the CRA 7 MLS. The minimum legal size limit in CRA 7 is 127 mm tail length (TL). We converted this to tail width (TW) using coefficients for a linear relationship between tail length and tail width for CRA 7 (Table 9).

Table 9: Coefficients of the relation between tail width and tail length in CRA 7 from Breen et al. (1988). TW = a + bTL

	a	*b*	*TW*
Male	-2.43	0.378	45.6
Female	-2.78	0.391	46.9

5.9 Starting conditions

Because the operating model incorporates stock-recruitment relations, the estimate of average recruitment from the 2000 NSS assessment is inappropriate. Rather, we assume that the population in 2000 is in equilibrium with the exploitation rate estimated from the most recent NSS assessment (Bentley et al. 2001). Those authors estimated a range of 41–59% exploitation rate.

The starting population is burned in with the particular movement dynamics, settlement dynamics, exploitation rate and an arbitrary fixed virgin recruitment. It is assumed that virgin recruitment is distributed as 20% to Otago, 30% to Stewart Island and 50% to Fiordland.

When the population reaches equilibrium with the exploitation rate, a catchability coefficient is calculated as a simple ratio between the equilibrium vulnerable biomass and the observed CPUE in 1999 (Table 10):

$$q = \frac{CPUE_{1999}}{B_{eq}}$$

Similarly, a scalar Q between the equilibrium catch (the product of the vulnerable biomass and the exploitation rate) and observed catches in 1999 (Table 10) is calculated:

$$Q = \frac{C_{1999}}{B_{eq}\overline{U}}$$

The calculated Q and q are used to scale the simulated catch and CPUE respectively.

Table 10: Mean CPUE and annual commercial catch in each area for 1999.

Area	Standardised CPUE (kg/potlift)	Catch (t)
Otago	0.32*	56.5
Stewart Island	1.00*	94.0
Fiordland	1.00*	615.8
CRA 7 + CRA 8	0.75#	756.3

5.10 Evaluation methods

We evaluated 376 situations: for each of the Joint, Separate and Amalgamated management strategies we used five levels of each of the three parameters of the rule (Table 12, discussed further below), giving 375 situations, plus the Current management strategy. For each of the 376 situations modelled, a parameter vector was obtained from the set obtained in Markov chain - Monte Carlo simulations in the 2000 assessment. There were 1000 samples.

In each of the 376 000 runs, stochastic process and observation error were simulated as described above, and a random state-of-nature was obtained with respect to the stock-recruit dynamics and migration (Sections 5.4 and 5.7). The process error, observation error, state-of-nature distributions and projection errors are summarised in Table 11. Random recruitment variation was based on the mean of the most recent 10 recruitment deviations from the assessment. Each simulation was 25 years from 2001.

Each of the performance indicators shown in Table 1 was calculated for every run. The results were read into a database that permitted of various queries.

Thus the evaluation procedure addressed realism and uncertainty by incorporating:

- assessment results with respect to the current state of the stock and likely dynamics parameter values,
- uncertainty with respect to parameter values and the current state of the stock,
- uncertainty about interactions of the three sub-stocks in CRA 7 and CRA 8, and
- the unpredictability of future recruitment.

The results of this procedure should not be viewed as predictions of what is likely to happen under any rule, but rather as a comparison of the likely relative performance of the various rules against each other.

Table 11: Parameter distributions used in simulations. F(x): fixed at x; U(a,b): uniform distribution from a to b; Po: chosen from the posterior distribution; L(u,s): lognormal distribution with mean u and standard deviation s.

Parameter	Distribution
Egg production a	F(0.06)
Egg production b	F(3.18)
Standard deviation of larval survival	U(0.5,1)
Density dependence in settlement Z	U(0.75,0.95)
Growth parameters G50 and G80 for each sex	Po
GrowthCV	F(0.373)
GrowthStdevMin	F(1)
Natural mortality rate M	Po
Migration:	
Difference between size at 50% maturity and size with 50% probability of migrating	U(-15,-5)
a (Table 8)	U(0.15,0.45)
b (Table 8)	U(0.15,0.45)
c (Table 8)	U(0.10,0.80)
Observation error for CPUE	L(1,0.2)

6. EVALUATION OF STOCK MANAGEMENT STRATEGIES

In the first phase of evaluations we simultaneously evaluated each of the four stock management strategies: Current, Joint, Separate(A) and Amalgamated. Within each of these strategies we evaluated different decision rules. The Current strategy involved only one rule; the other three involved five different values for each of the three parameters in the new rule type, giving 125 candidate rules for each and 376 candidates overall. The combinations simulated are summarised in Table 12.

Table 12: Summary of situations simulated in phase one of the evaluations.

Strategy	MLS	Targets	Rule	Rule parameters	number
Current	different	3.67 kg/lift in 2014	old	N=3, S=0.8 min=max=0.20	1
Joint	different	1.53 kg/lift in 2011	new	N={1,2,3,4,5} W={0.2,0.4,0.6,0.8,1.0} S={0.25,0.50,0.75,1.00,1.25}	125
Separate(A) in CRA 7	different	n.a.	CER		
Separate(A) in CRA 8	different	1.90 kg/lift in 2011	new	as for Joint	125
Amalgamated	same	1.90 kg/lift in 2011	new	as for Joint	125

For the Current strategy, the *Bmsy* estimate from the 1996 assessment was 3.67 kg/potlift.

In all but the Amalgamated strategy, different MLSs were used for CRA 7 and CRA 8, as at present. The CRA 7 MLS is 46 mm tail width for both sexes; the CRA 8 MLS for males is 54 mm and for females 57 mm tail width.

For the Separate(A) strategy in CRA 7, we simulated a constant exploitation rate strategy based on the standard errors from the regression between second-week CPUE and annual CPUE (see Table 5), the most accurate of the predictors tested. For the constant-exploitation rate (CER) strategy, the start-of-year vulnerable biomass was converted to CPUE using a catchability coefficient, adding observation error, generating a prediction with error using the regression coefficients and associated standard errors and then multiplying by the catch scalar to obtain the TACC.

In the Amalgamated strategy, the MLSs for both CRA 7 and CRA 8 were set to the CRA 8 values. The target for rebuilding in the Joint strategy was based on the 1979-82 mean CPUE for CRA 7 and CRA 8 combined; for the Separate(A) and Amalgamated strategies it was based on the mean from CRA 8 only. Under this strategy it was assumed that the current CRA 7 TACC of 111 t would be redistributed in the NSS in proportion to the available biomass.

6.1 Relative performance of stock management strategies

The results from 376 000 simulations are summarised in Figure 9 through Figure 15. All results from the 1000 runs for each individual rule were reduced to a mean, and for each management strategy the figure shows the distribution of these means. For the Current strategy there was only one rule, so only one value is shown – the mean of the 1000 runs. Overall catch (sum of catches in the three areas) is shown, and the appropriate CPUE and rebuilding target are used for each strategy.

The Current strategy had the lowest mean overall catch (Figure 9), least number of years below the starting CPUE (Figure 10), but the highest number of years (nearly all) with catches less than the start (Figure 11). The pattern in mean CPUE (Figure 12) was the opposite of that in mean catch (Figure 9), showing the trade-off between rebuilding rate (high CPUE) and catch.

Between the Joint and Separate(A) strategies, there was little difference in the CPUE indicator – both had more years than Current with CPUE below the start value; both also had fewer years with catch below the starting value. The Amalgamated strategy had the fewest years with catch below the starting catch, the highest years with low CPUE, and the highest mean catch.

Figures 13 through 15 show nine performance indicators for each sub-area for each strategy.

For Otago (Figure 13), the Amalgamated strategy produces the least catch from CRA 7: this is because the MLS increases at the start of the strategy, and CRA 7 quota is taken instead from CRA 8. This change also leads to low CPUE. Of the other strategies, Current has the lowest catch and highest CPUE, as in the overall results.

Bteween Stewart Island (Figure 14) and Fiordland (Figure 15) the results show many similarities. The Current strategy, with its high rebuild target, gave the lowest catch, highest CPUE and size diversity. The Amalgamated strategy gave the highest mean catch, and the fastest rebuild.

These results suggest first that the Current strategy (i.e., the current decision rule for the NSS stock) is a severe one: in the simulations the catch was cut so that it averaged only 325 t over the 25 year-runs in the three areas, whereas other strategies had much higher catches and still increased biomass (to the lower target) in reasonable times.

Second, they suggest that the Amalgamated strategy might be better in some respects than the Joint or Separate(A) strategies. Amalgamated does better in catch overall ; it has the lowest mean rebuild time in Fordland, and in Stewart Island is about the same in rebuild time as the Joint strategy. In other indicators there is little difference among the strategies.

In turn, the good performance of the Amalgamated approach suggests a yield-per-recruit advantage. Its major features are the common fishstock and common MLS. That this strategy outperforms the broadly similar Separate(A) might result from current growth overfishing in CRA 7.

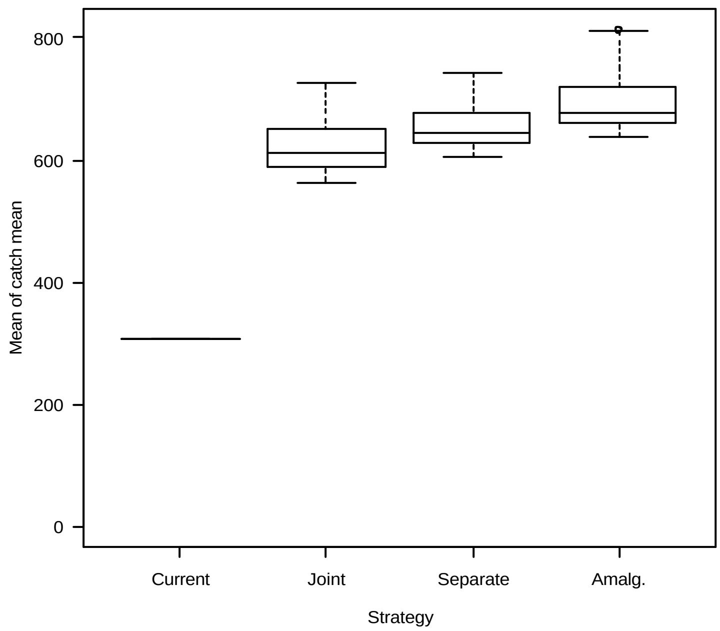

Figure 9: The mean catch distributions for each of 4 stock management strategies. Results shown are from the 1000 individual runs for each of 175 individual rules, except for the Current strategy where there was only one rule. The central horizontal bar shows the median, the box shows 25th and 75th percentiles, the outer horizontal bars show the 5th and 95th percentiles and circles show "outliers".

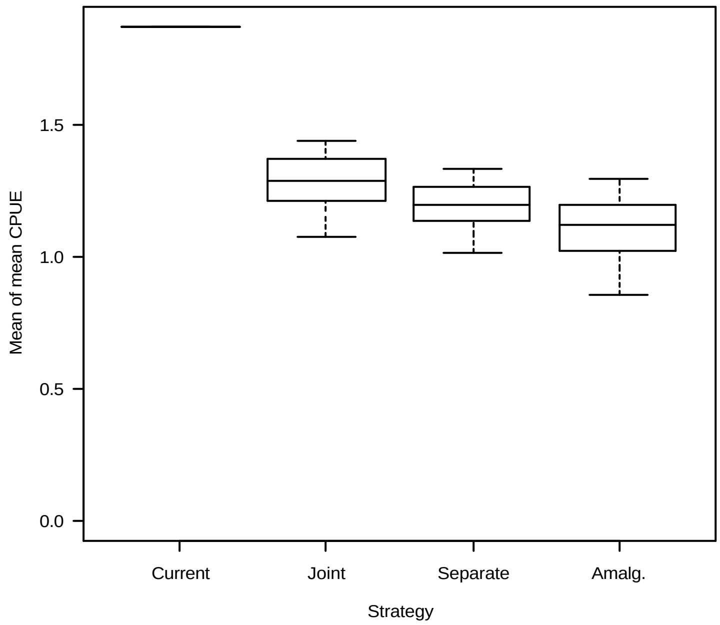

Figure 10: The distributions of the mean CPUE in each of the four management strategies. For details see the Figure 9 caption.

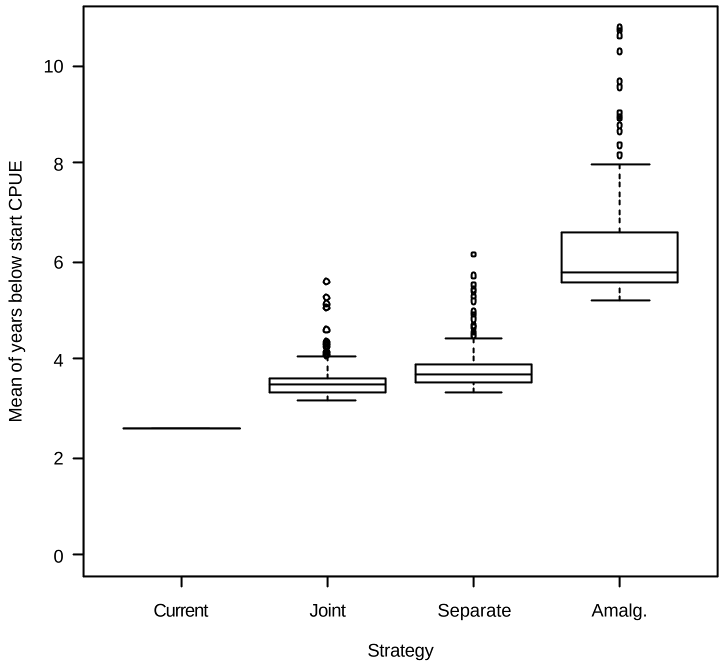

Figure 11: The distributions of the mean number of years in which CPUE was below the starting value in each of the four management strategies. For details see the Figure 9 caption.

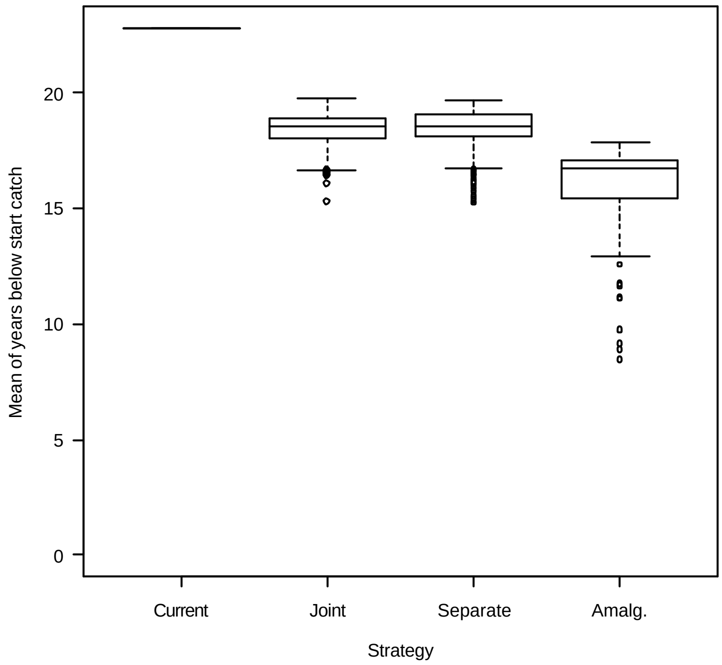

Figure 12: The distributions of the mean number of years in which catch was less than the starting value in each of the four management strategies. For details see caption for Figure 9.

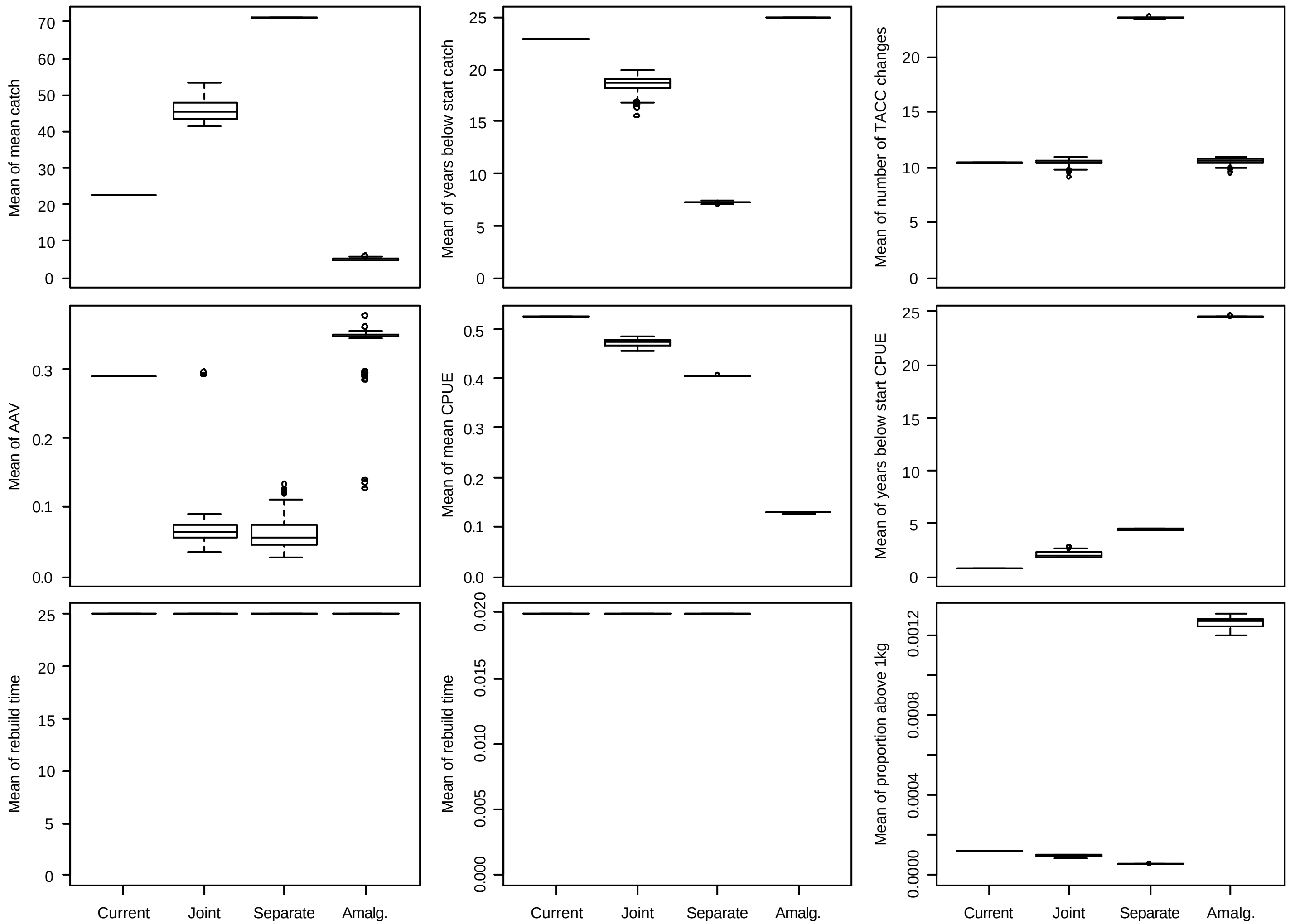

Figure 13: The distributions of means for nine performance indicators based on the Otago area only under four management strategies. For details see caption for Figure 9.

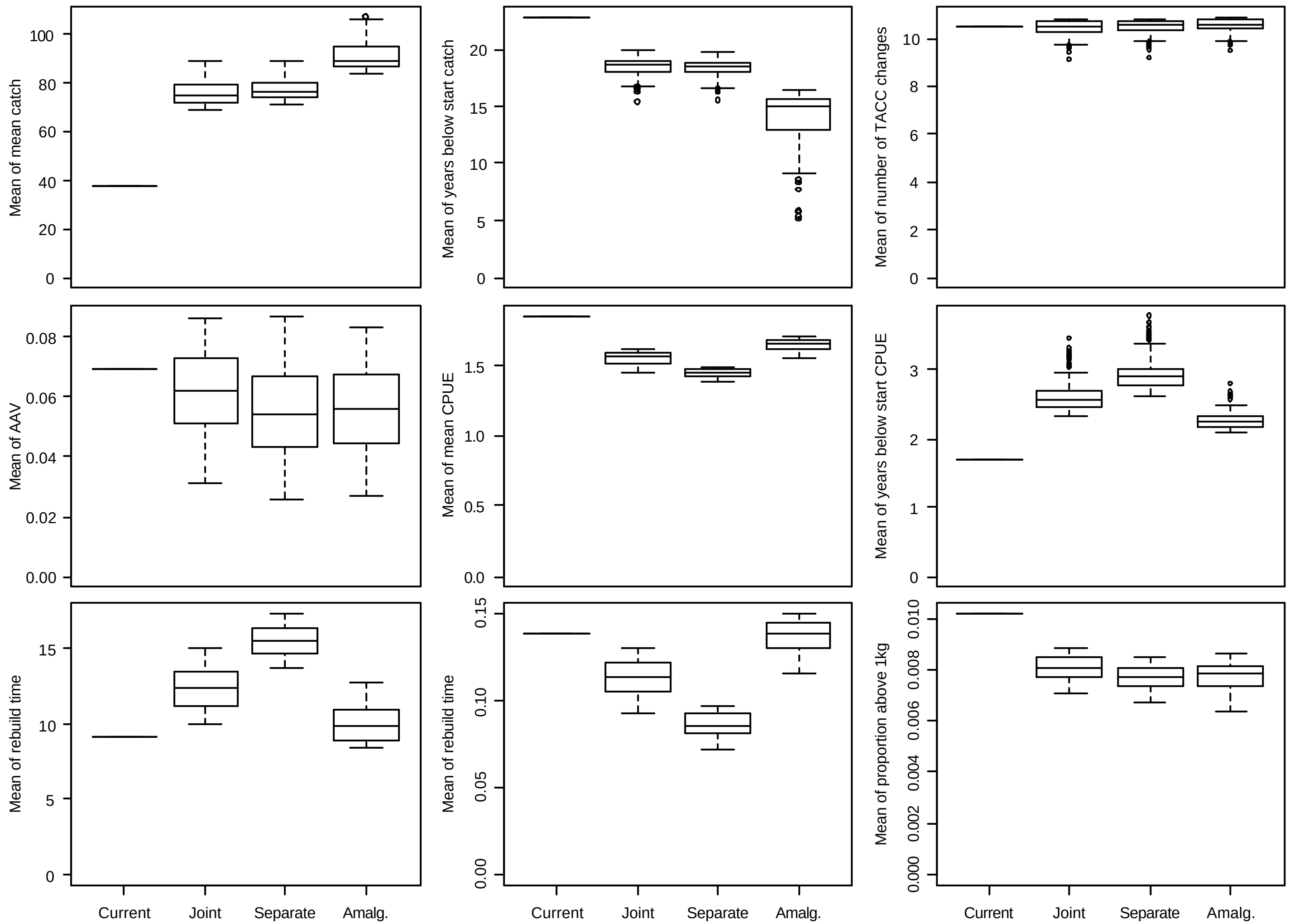

Figure 14: The distributions of means for nine performance indicators based on the Stewart Island area only under four management strategies. For details see caption for Figure 9.

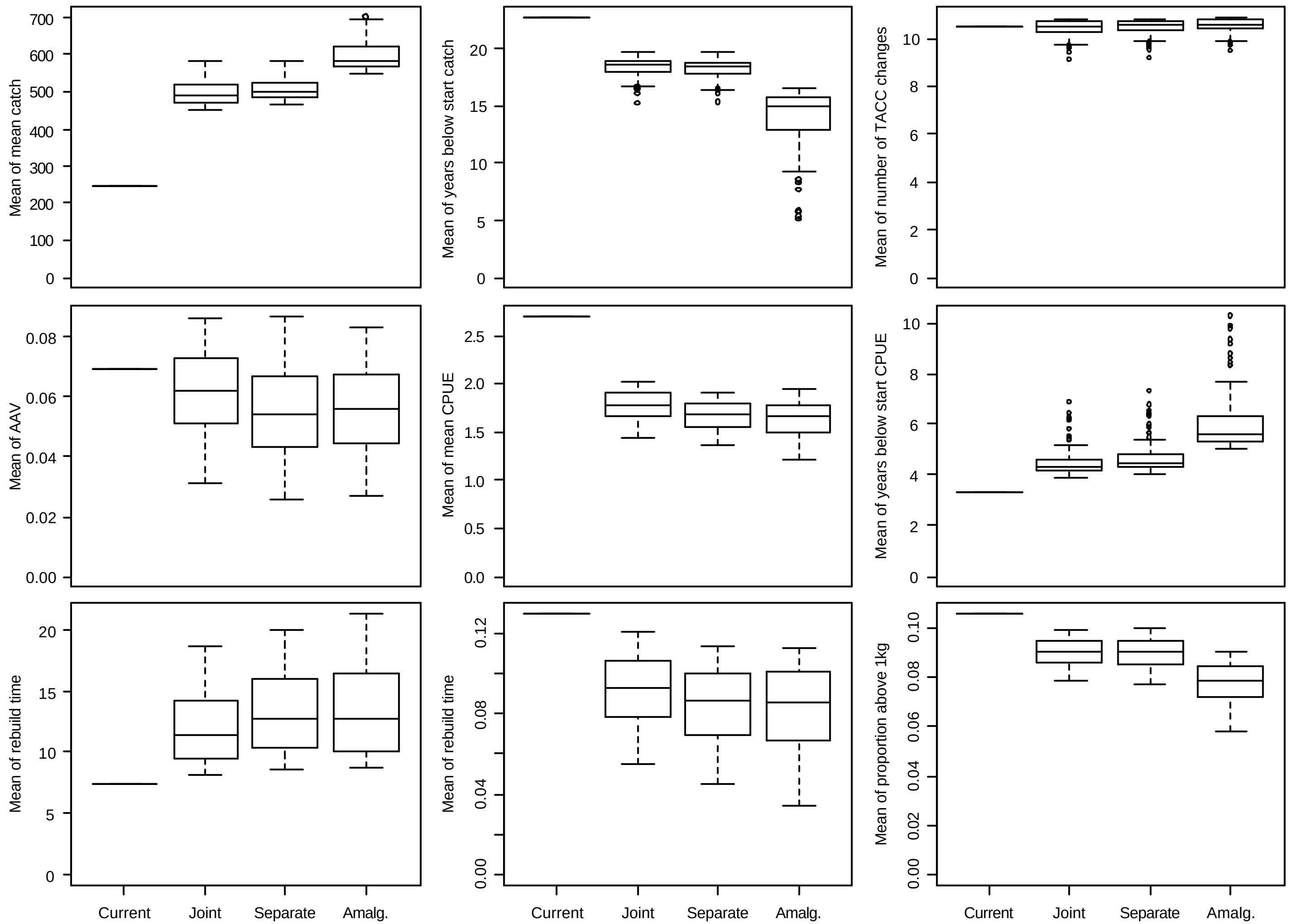

Figure 15: The distributions of means for nine performance indicators based on the Fiordland area only under four management strategies. For details see caption for Figure 9.

6.2 Sensitivity to movement parameters

The Working Group requested examination of alternative distributions of movements, and for that sensitivity test these values were chosen:

a Uniform(0.05,0.45)
b Uniform(0.00,0.20)
c Uniform(0.10,0.80)

This test was made under the Amalgamated strategy, which might have been expected to produce the greatest effect. As Table 13 shows, the alternative movement parameters resulted in increases in most performance indicators, but the changes were all relatively small.

Table 13: Comparing the original and an alternative distribution of migration parameters (see Table 8) on the performance indicators indicated, for all rules under the Amalgamated strategy.

		Original	Alternative	% Change
Overall	Mean catch	678.6	697.2	2.7
	Mean CPUE	1.14	1.16	2.0
Stewart Island	Mean catch	89.2	91.2	2.2
	Mean CPUE	1.67	1.76	5.2
	Mean rebuild time	6.1	6.1	0.1
Fiordland	Mean catch	584.5	597.4	2.2
	Mean CPUE	1.68	1.67	-0.8
	Mean rebuild time	10.8	10.8	0.5

6.3 Relative performance of individual decision rules

The relative performance of rules was similar under each of the stock management strategies. Although stock management strategies have different overall levels of performance indicators, there was a high correlation between the mean values of performance indicators for a given rule between stock management strategies. This was true for both individual areas and overall performance indicators: for instance, rule 155 is always at the bottom left-hand corner of the graphs in Figure 16. This result suggested that the choice of decision rule is insensitive to the stock management strategy taken.

6.4 Choice of stock management strategy

The NRLMG discussed the results described above in May 2002. Although the Amalgamated strategy looked interesting, the NRLMG discussed logistic realities of changing the management of CRA 7 and CRA8, concluding that the Amalgamated strategy could not be implemented in the time frame being considered. The NRLMG agreed that the evaluation work should proceed with one strategy only: Separate(B) (see Section 3).

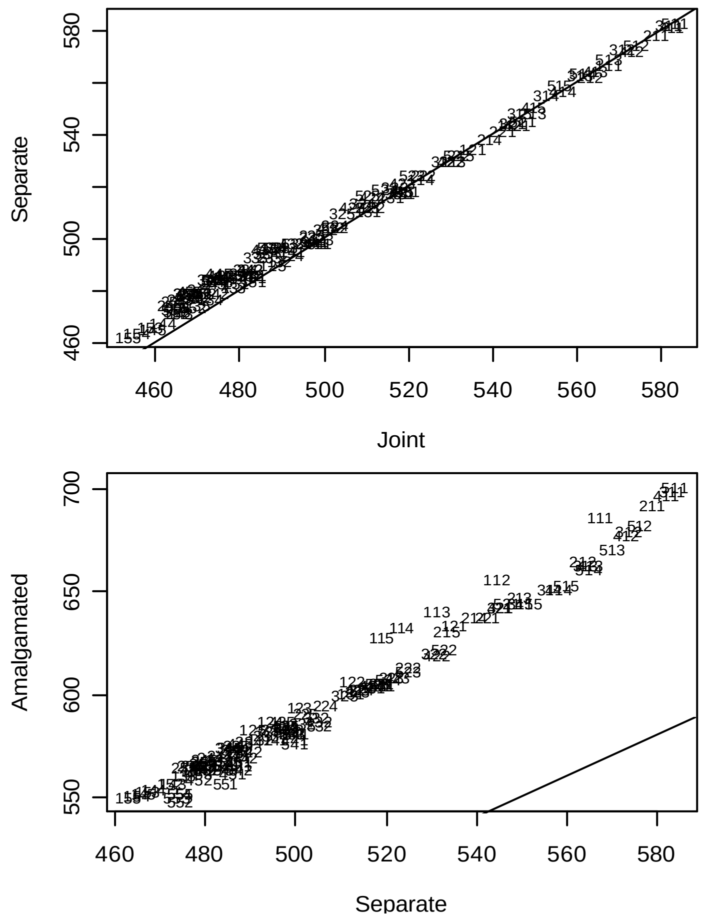

Figure 16: Correlation between the mean annual catch for Fiordland obtained by the same rule under different stock management strategies (a) joint v separate (b) separate v amalgamated. The line of equality is shown. The candidate rule number is used as the data point.

7. EVALUATION OF REMOVING DECISION RULE TIME LAG

The current decision rule has a one-year lag in management response. For example, catch and effort data from the 1999–2000 fishing year were analysed during 2000 for a management decision for the 2001–02 year. This lag may affect the responsiveness of management to fluctuations in the stock size. CRA 8 stakeholders requested us to examine the potential for removing this lag.

We examined the potential for using catch and effort data from only part of a fishing year to estimate a CPUE index. Since 1993–94, at least 80% of the TACC in CRA 8 has been taken by the end of December and at least 91% by the end of January (Table 14). This might allow a decision rule to be operated at the end of a fishing year (say between January and March) to effect a TACC change for the following fishing year.

We used the catch-effort data set in CRACE (N. Bentley, P. Starr and T. Kendrick, unpublished data) for calculating standardised CPUE indices. Subsets of this data set were created by including data from only part of each fishing year (for example April-November). For each subset, for each fishing year, 1979–80 to 2000–01, we estimated the annual standardised CPUE index. This was done by applying the month and area coefficients obtained from the 2001 CPUE standardisation model for CRA8 to each record of ln(CPUE) by vessel-month-area combination and then taking the mean of those values by year.

Table 14: Cumulative catch percentage by fishing year (N. Bentley, P. Starr and T. Kendrick (unpublished data).

Fishing year	9	10	11	12	1	2
1979	30	55	74	83	92	97
1980	28	53	74	87	94	97
1981	38	64	83	92	97	99
1982	33	62	72	82	90	96
1983	23	42	64	80	92	98
1984	38	63	78	89	95	99
1985	47	68	82	91	95	98
1986	33	53	73	85	93	97
1987	32	52	71	84	92	98
1988	26	43	61	75	91	98
1989	4	27	55	72	86	94
1990	31	48	66	76	88	95
1991	27	46	62	76	89	96
1992	33	48	63	77	86	96
1993	53	73	84	91	95	98
1994	45	63	74	86	95	99
1995	40	61	79	86	94	98
1996	38	60	78	88	96	98
1997	40	62	76	87	96	100
1998	31	46	67	80	91	97
1999	47	67	82	89	96	98
2000	57	72	85	91	97	100

$$\hat{I}_t = \frac{\sum_{i}^{n_t} \ln(CPUE_i) - M_{m_i} - A_{a_i}}{n_t}$$

where $\hat{I}_y$ is the estimate of the standardised CPUE index for year y, M and A are the month and area coefficients and m_i and a_i are the months and area for record i.

Correlations between the predicted index and the index actually calculated from the entire year’s data were examined. As expected, there was an improvement in the correlation with increasing size of the data subset (Figure 17). The correlation based on data to 31 December appears satisfactory, and there was little improvement in the correlation when using data from past that date.

There have recently been improvements in the speed with which CELR forms are submitted by fishers and the speed with which they are entered into the Ministry of Fisheries databases. However, there is still likely to be at least a 6 week delay in obtaining data and a 2 week delay for error checking the data and performing standardisations. Given a 31 December cut-off date, this would give a result from the decision rule at the beginning of March, leaving only about a month before the 1 April start of the season. This is a very tight timeframe. There would be a risk that the data timeframe was not met and risk of a sudden change in the seasonal distribution of fishing effort, with a lower proportion of catch taken by the end of December. The Ministry of Fisheries representatives to the NRLMG indicated that this would be an unacceptably short time frame for the Minister to make a decision.

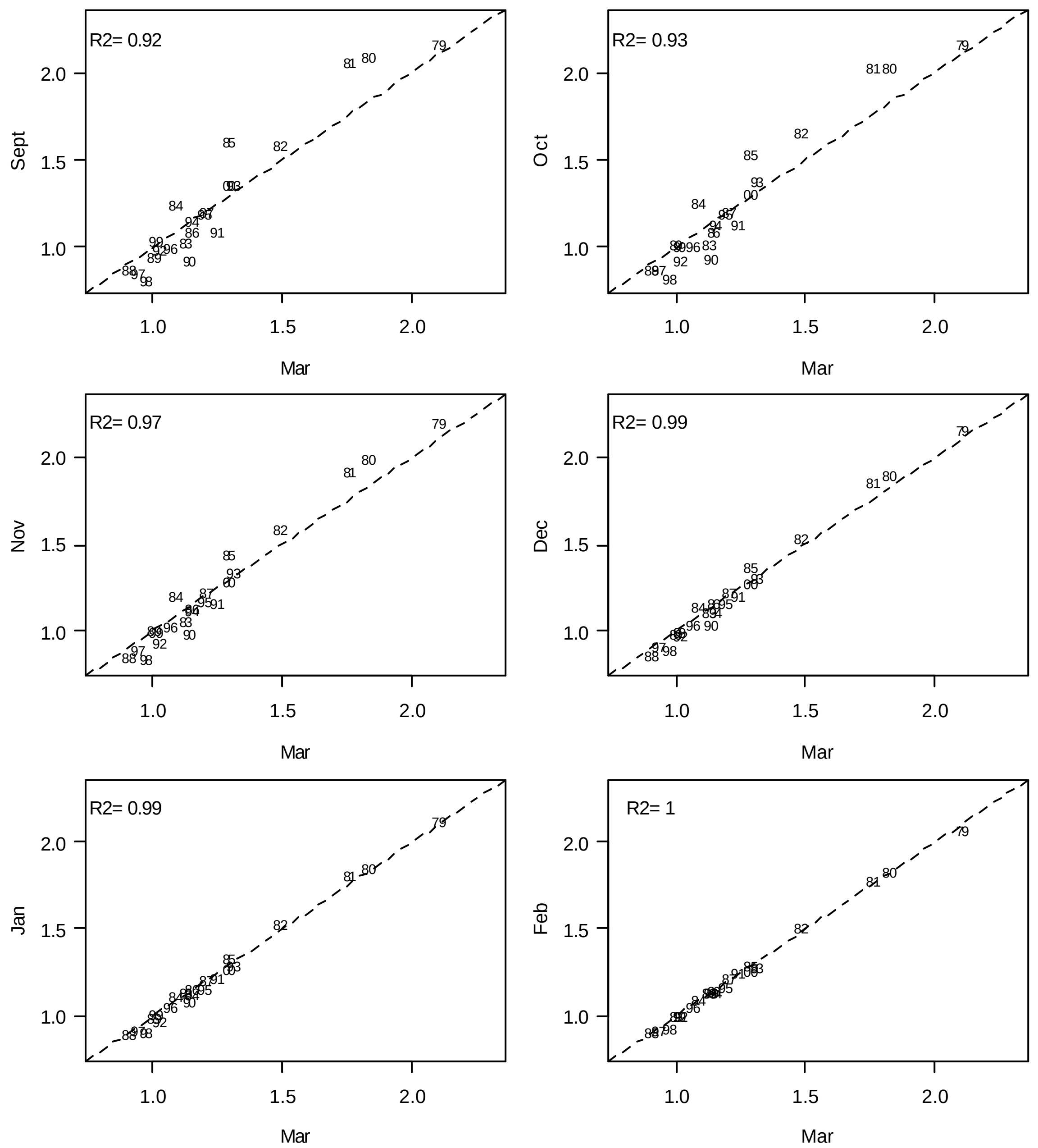

Figure 17: Relation between predicted annual CPUE based on data from April-September (y-axis) (top left), April-October (top right), April-November (middle left), April-December(middle right), April-January (lower left) and April-February, and the annual CPUE based on data for the entire fishing year (x-axis). Coefficient of determination (R^2) shown in top-left corner.

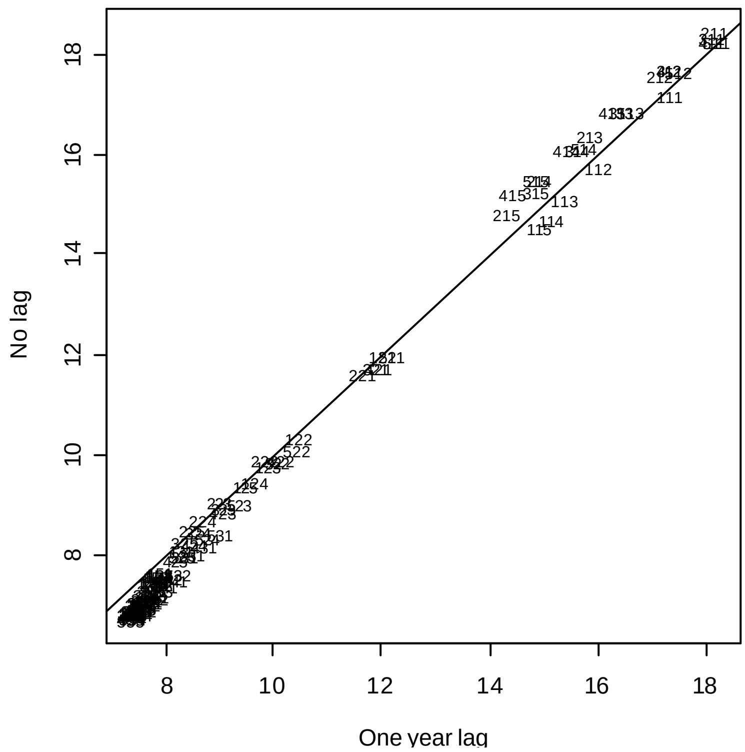

Figure 18: Relation between Fiordland rebuild time obtained with individual rules defined by levels of the rule parameters *N*, *W* and *S*, defined in Section 4.3) with (along the x-axis) and without (on y-axis) a lag. Rules are denoted by the levels of *N*, *W* and *S*.

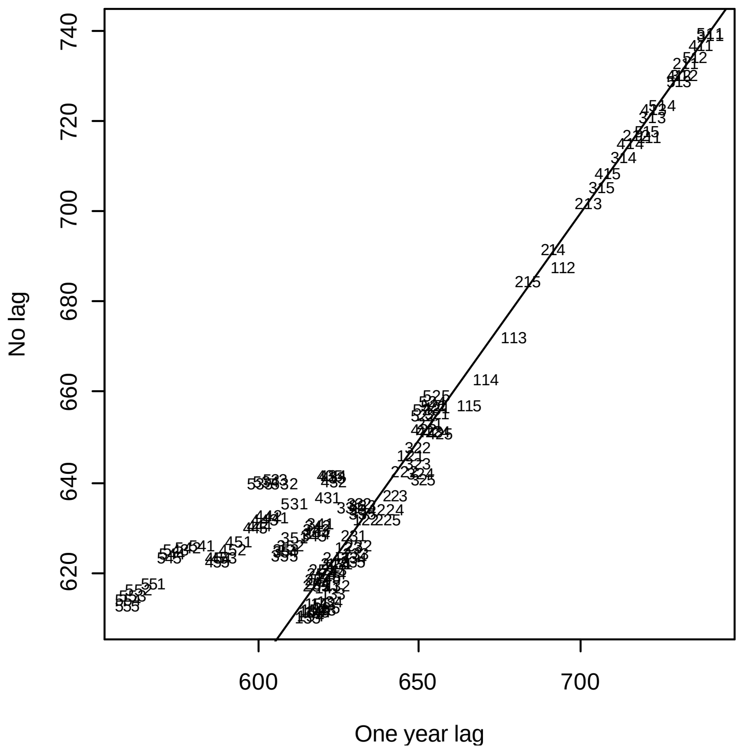

Figure 19: Relation between overall mean catch (t) obtained with individual rules defined by levels of the rule parameters *N*, *W* and *S*, defined in Section 4.3) with (along the x-axis) and without (on y-axis) a lag. Rules are denoted by the levels of *N*, *W* and *S*.

We performed simulations of decision rules without a lag to estimate the potential benefits in terms of the performance indicators: 1000 simulations were done for each of the 125 combinations of the decision rule parameters *N*, *W* and *S* (see Section 4.3). We compared the relative performance of each rule with and without a lag. Generally, there was little difference between mean values of performance indicators (e.g., mean rebuild time, Figure 18). However, for mean overall catch there were larger differences between the two types of rules for some combination of rule parameters (Figure 19). Rules with a high *N* and high *W* had significantly greater catch when the lag was removed. This is probably because those rules are naturally the least responsive to changes to stock size. Over all combinations of parameters there was a small improvement in performance indicators (Table 15).

Table 15: Comparison of some key performance indicators with a one-year lag and with no lag.

		One year lag	No lag	Difference
Overall	Mean catch	638.2	646.5	1.3
Fiordland	Mean CPUE	1.87	1.82	-2.6
	Mean rebuild (yr)	9.83	9.57	-2.6
	AAV	8.2%	8.0%	-1.8
Stewart Island	Mean CPUE	1.55	1.53	-0.9
	Mean rebuild (yr)	10.78	10.75	-0.3
	AAV	8.2%	8.0%	-1.8

7.1 Choice of decision rule lag

Given the risks involved and the minimal performance benefits of dropping the lag, the NRLMG agreed to leave the situation as it was with the 1997 rule, retaining a 1-year lag between the CPUE data and implementation of any change to catches.

8. EVALUATION OF DECISION RULE PARAMETERS

The results presented were obtained using only the Separate(B) stock management strategy with a 1-year response lag and with a latent year (the catch cannot be changed in two consecutive years).

Table 16: Mean values across all management strategies, 1000 parameter vectors and all values of the other rule parameters, for each of the parameter values for the performance indicators (from the Fiordland sub-stock only) shown. Indicators are defined in Table 1.

		Mean catch	%Catch low	%AAV	%CPUE low	Rebuild time	%Large
N	1	636	17.0	8.7	5.0	9.9	9.3
	2	645	16.9	8.3	4.7	9.7	9.5
	3	647	16.7	8.1	4.9	9.8	9.5
	4	639	17.0	8.0	4.8	9.8	9.6
	5	626	17.4	7.8	4.9	9.9	9.6
W	0.2	714	15.8	4.8	5.8	16.2	8.0
	0.4	647	17.5	6.5	4.8	9.8	9.3
	0.6	623	17.1	9.1	4.7	7.9	10.0
	0.8	608	17.3	10.0	4.5	7.6	10.2
	1	600	17.4	10.4	4.5	7.6	10.2
S	0.5	645	17.3	6.6	5.0	10.8	9.3
	0.75	640	17.0	7.7	4.9	10.1	9.5
	1	637	17.0	8.4	4.8	9.7	9.6
	1.25	635	16.9	8.9	4.8	9.4	9.6
	1.5	633	16.9	9.2	4.8	9.2	9.7

The effects of the individual rule parameters, averaged across all the effects of all other variables, are shown in Table 16. The effect of *N* was not great: smaller values gave slightly lower catches. The effect of *W* was much greater: smaller values gave higher mean catches and lower CPUE. However, the number of years with lower than initial catches increased as *W* increased. The effect of *S* was smaller than that of *W*: smaller values gave higher catches and lower CPUE.

The interactions among rule parameters are explored in Figures 20 and 21 for three performance indicators. These are averaged across the 1000 runs for each of 125 candidate rules. The slopes of the surfaces show that, using Fiordland as the example (Figure 20), the shortest rebuild time is produced by the combination of high *W* and high *S*. For mean catch (Figure 21), *S* is more important than *W*, and the highest mean catch is always produced by the smallest values for *W* and *S*.

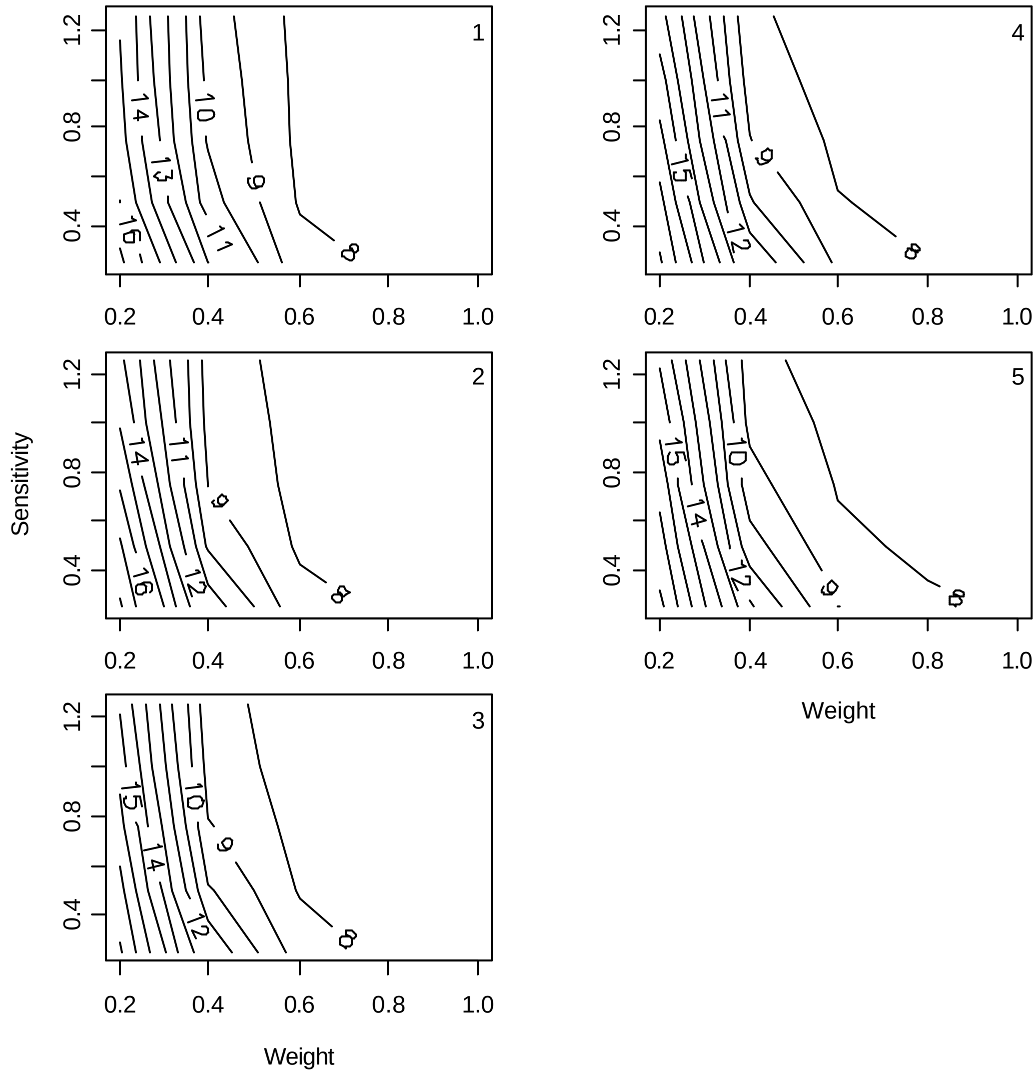

Figure 20: Response surfaces for mean rebuilding time in Fiordland created by the values of decision rule parameters *S* and *W* shown, averaged across all 125 candidate rules. Each figure shows the surface with *N* fixed at the value shown in the top right corner.

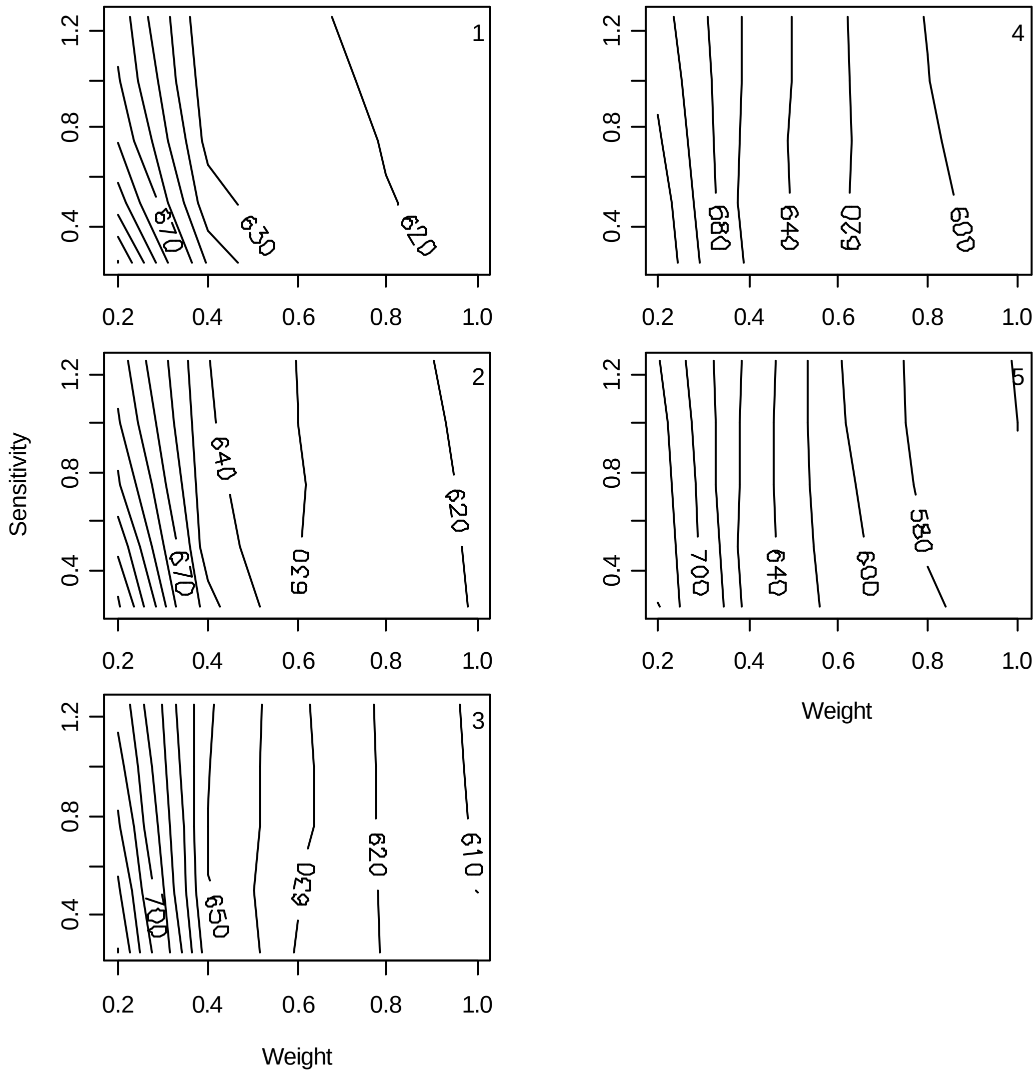

Figure 21: Response surfaces for mean catch created by the values of decision rule parameters *S* and *W* shown, averaged across all 125 candidate rules. Each figure shows the surface with *N* fixed at the value shown in the top right corner.

The results shown so far did not address the issue of variability within a candidate rule. For instance, Figures 22 and 23 show the distributions of rebuild times and mean catch, respectively, from 1000 25-year runs for nine specific candidate rules from Table 17. Mean catches are similar among these rules, but the distribution among runs is wide: from 400 t to 1000 t. This issue was addressed in selecting a final rule.

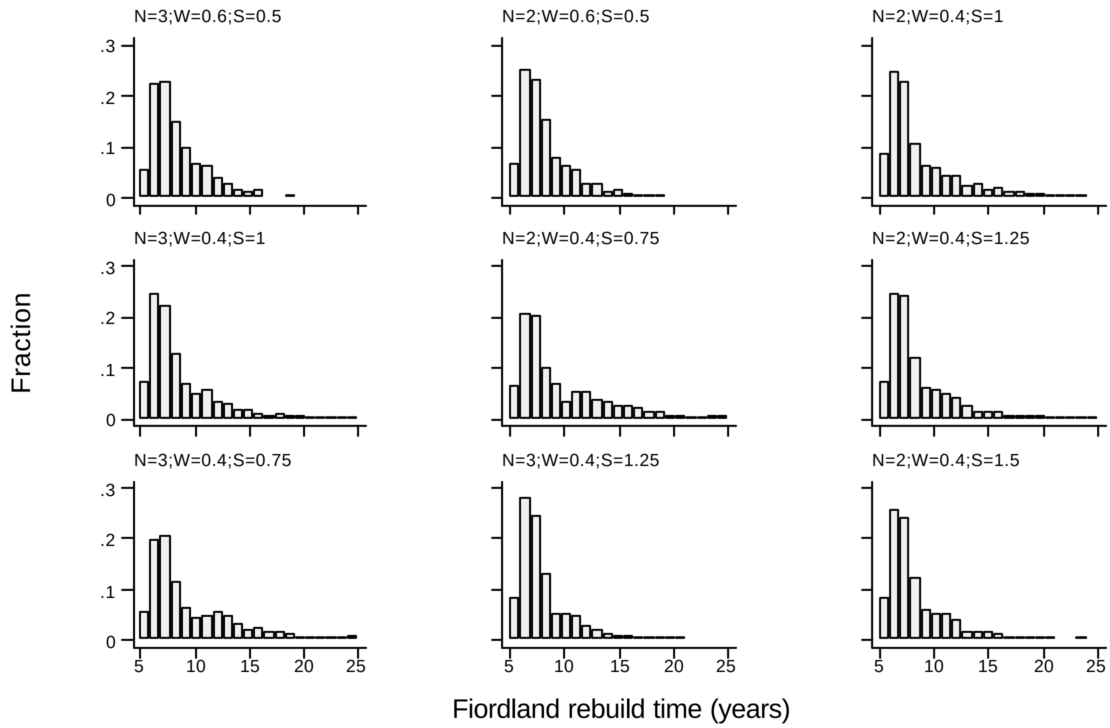

Figure 22: Distributions of rebuild times in Fiordland for the first nine rules presented in Table 17. Rule 1 is top left, Rule 2 centre left, and so forth.

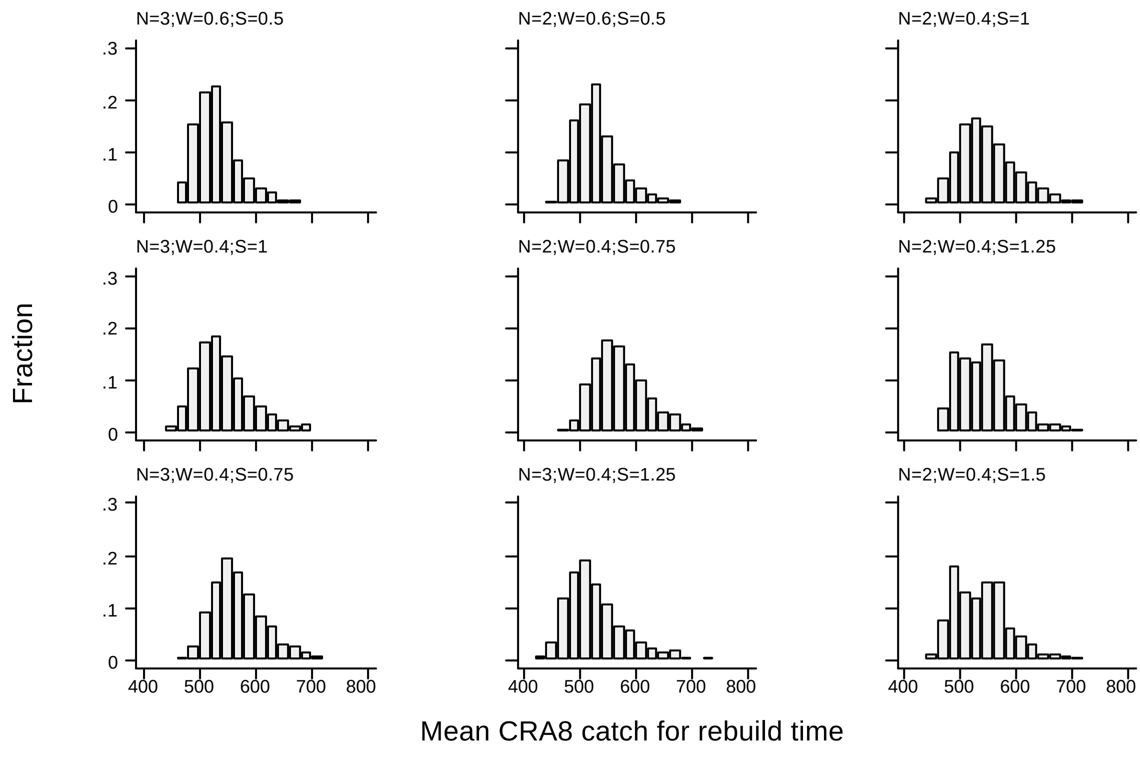

Figure 23: Distributions of mean CRA 8 catch during the rebuild period for the first nine rules presented in Table 17.

Table 17: For the 20 final candidate decision rules discussed in the text, their probabilities meeting the three criteria described in the text (rebuilding within 14 years, maintaining CPUE above the start level, and minimising interannual variation of indicators) (columns 4-6) and the probability of meeting all three together (column 3). The CPUE criterion (column 5) is set to test whether more than 8 of 25 years in each simulation are below than the starting CPUE. These probabilities are based on Fiordland indicators only. Rules are ranked from highest to lowest joint probability; rebuild times are in years; catches are in tonnes. Columns 7-10 show additional indicators requested by the NRLMG. The "rebuild catch" for CRA 8 is measured only during the period before the target has been reached.

Number	Rule	Joint probability	Rebuild<=14 years	CPUE<=start CPUE	%AAV <=0.10	Mean rebuild time	Median rebuild time	Mean CRA8 rebuild catch	Mean CRA8 25-year catch
1	*N*=3; *W*=0.6; *S*=0.5	0.87	0.97	0.96	0.94	8.3	7	534	599
2	*N*=2; *W*=0.6; *S*=0.5	0.85	0.96	0.96	0.91	8.1	7	530	600
3	*N*=2; *W*=0.4; *S*=1	0.83	0.92	0.96	0.94	8.6	7	550	610
4	*N*=3; *W*=0.4; *S*=1	0.82	0.93	0.93	0.95	8.5	7	545	619
5	*N*=2; *W*=0.4; *S*=0.75	0.81	0.86	0.95	0.98	9.5	8	574	613
6	*N*=2; *W*=0.4; *S*=1.25	0.81	0.94	0.95	0.90	8.4	7	546	608
7	*N*=3; *W*=0.4; *S*=0.75	0.79	0.88	0.92	0.99	9.5	8	571	618
8	*N*=3; *W*=0.4; *S*=1.25	0.76	0.95	0.93	0.84	8.0	7	528	618
9	*N*=2; *W*=0.4; *S*=1.5	0.74	0.94	0.94	0.83	8.2	7	540	608
10	*N*=2; *W*=0.4; *S*=0.5	0.67	0.72	0.95	1.00	11.4	9	610	620
11	*N*=3; *W*=0.4; *S*=0.5	0.67	0.73	0.93	1.00	11.5	9	610	622
12	*N*=3; *W*=0.4; *S*=1.5	0.66	0.96	0.93	0.72	7.7	7	516	619
13	*N*=3; *W*=0.6; *S*=0.75	0.65	0.98	0.96	0.69	7.7	7	507	601
14	*N*=2; *W*=0.6; *S*=0.75	0.64	0.98	0.96	0.68	7.5	7	505	600
15	*N*=2; *W*=0.6; *S*=1	0.56	0.98	0.96	0.58	7.5	7	505	598
16	*N*=3; *W*=0.6; *S*=1	0.44	0.99	0.97	0.47	7.4	7	492	602
17	*N*=2; *W*=0.6; *S*=1.25	0.42	0.99	0.96	0.43	7.4	7	502	598
18	*N*=3; *W*=0.6; *S*=1.25	0.40	0.99	0.97	0.41	7.4	7	492	600
19	*N*=2; *W*=0.6; *S*=1.5	0.33	0.99	0.95	0.34	7.4	7	500	598
20	*N*=3; *W*=0.6; *S*=1.5	0.30	1.00	0.97	0.30	7.3	7	489	599

At a meeting in early June 2002, the NRLMG agreed that the parameter *N* should be restricted to 2 or 3 and that the weight parameter *W* should be restricted to 0.4 and 0.6. These changes reduced the family of rules under consideration from 125 in the initial evaluations to 20 in this phase.

At this stage the NRLMG also agreed on a set of three criteria by which the alternatives could be ranked. These were:

- the new rule must rebuild the fishery to the target CPUE within 14 years with a high probability;
- it must result in CPUE higher than the starting CPUE in at least 17 of the next 25 years with a high probability; and
- it must result in an average annual variation in catch of less than 10% with a high probability.

From the database of individual run results for the 20 rules under the Separate(B) strategy, it was possible to collate the probability (frequency among the 1000 runs) of each rule meeting each of these three specifications, and also to determine the probability of each rule meeting all three specifications at once. These are shown in Table 17.

In Table 17, the 20 candidate rules are ranked from highest to lowest in their probability of meeting all three specifications. The “best” rule in this respect met the specifications in 87% of runs; the worst in only 30%. The top nine rules varied from 74 to 87%.

For Rules 1 to 9, the median time to rebuild was 7 or 8 years (Table 17, Figure 22). The mean was higher, from 8.0 years (Rule 8) to 9.5 years (Rules 5 and 7). These are all less than the target time of 10 years. Mean catch during the rebuild period varied substantially (Table 17 and Figure 23).

Because the target time to rebuild was 10 years, and because of the trade-off between rebuilding time and catch during the rebuild, a short mean rebuild time was not necessarily good. The trade-off can be seen in Table 17, where the longer times to rebuild (Rules 5 and 7) are associated with much higher mean catches during the rebuild period.

The average time to rebuild is less than the target for all rules. Probably there is a trade-off between this and meeting the specification of rebuilding within 14 years. A rule with average time to rebuild of 10 years would probably have a substantial tail of the distribution with rebuild times greater than 14 years.

9. DISCUSSION

The decision rule process has worked well for the NSS stock for 6 years. Although the current rule is not popular, it produced two catch reductions which were needed to prevent further reductions in CPUE and to start the rebuilding, and stakeholders want to see the decision rule framework maintained.

We examined candidates for a rebuilding rule only. Work is proceeding on designing and testing rules suitable for maintaining biomass near a target value. By the time the NSS stock is rebuilt, such rules should be well developed, and this rule should be replaced with a more appropriate maintenance rule.

After seeing the information presented above, the NRLMG chose Rule 7 from Table 17, as a candidate with a high probability of meeting the three criteria they defined (Section 8) and with a mean rebuild time close to the target of 10 years. The Minister approved the change, and this rule is now in operation for the NSS stock. It will be evaluated for the first time in late 2002, for possible change to the allowable catch for the 2003–04 fishing year, starting April 2003.

Review of the rule should be automatic and mandatory after some fixed period such as 5 or 6 years, or sooner if rebuild is achieved. Review of the rule during its agreed tenure of 5 or 6 years would be desirable only if the fishery experienced some extreme fluctuation, or there were other indications that the rule was not working as planned.

The rule would likely work slightly better if there were no lag between the CPUE from year *t* and the result of the rule for year *t*+1 (section 7). The pre-recruit information does not appear to contain enough information to predict CPUE in year *t* from previous catch sampling (section 4). Early in-season CPUE data appear to predict the whole year's CPUE reasonably well (e.g., Figure 17), but the innate lag in the management system, requiring several months for consultation and publication, preclude this approach. In simulations the lag appeared to degrade mean performance by only a few percent (Table 15).

Although only one stock management strategy was logistically feasible in the short time-frame for the choice of decision rule here, investigation of the four strategies suggested that the Amalgamated strategy might have higher mean catches and a shorter mean rebuild time for Stewart Island and Fiordland (Figures 14 and 15). Under this strategy CRA 7 and CRA 8 would have a common TAC and MLS regime, and quota could be caught in either area. In the short term, most quota would be caught in CRA 8, because most lobsters in CRA 7 would be too small to catch legally. That the Amalgamated strategy does better than the Separate(A) strategy suggests possible growth over-fishing in CRA 7.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

Annala, J.H.; Bycroft, B.L. (1993). Movements of rock lobsters (*Jasus edwardsii*) tagged in Fiordland, New Zealand. *New Zealand Journal of Marine and Freshwater Research 27:* 183–190.

Bentley N.; Breen, P.A.; Starr, P.J.; Sykes, D.R. (2003). Development and evaluation of decision rules for management of New Zealand rock lobster fisheries. *New Zealand Fisheries Assessment Report 2003:29.* 14 p.

Bentley N.; Breen, P.A.; Starr, P.J.; Kendrick, T.H (2001) Stock assessment of CRA3 and NSS stock of rock lobster in 2000. *New Zealand Fisheries Assessment Report 2001/69.* 28 p.

Booth, J.D. (1997). Long-distance movements in *Jasus* spp. and their role in larval recruitment *Bulletin of Marine Science 61(1):* 111–128.

Booth, J.D.; Breen, P.A. (1992). Stock structure in the New Zealand rock lobster *Jasus edwardsii. N.Z. Fisheries Assessment Research Document 92/20*. 20 p. (Unpublished report held in NIWA library, Wellington).

Breen, P.A.; Booth, J.D.; Tyson, P.J. (1988). Feasibility of a minimum size limit based on tail width for the New Zealand rock lobster *Jasus edwardsii*. *New Zealand Fisheries Technical Report 6.* 16 p.

Breen, P.A.; Kendrick, T.H. (1998). The 1996 assessment of the New Zealand red rock lobster (*Jasus edwardsii*) fishery. *New Zealand Fisheries Assessment Research Document 98/13.* 42 p. (Unpublished report held in NIWA library, Wellington).

Breen, P.A.; Kim, S.W.; Starr, P.J.; Bentley, N. (2002). Assessment of the red rock lobsters (*Jasus edwardsii*) in area CRA 3 in 2001. *New Zealand Fisheries Assessment Report 2002/27.* 82 p.

Breen, P.A.; Kim, S.W.; Andrew, N.L. (2003). A length-based Bayesian stock assessment model for abalone. *Marine and Freshwater Research 53.* (in press).

Butterworth, D.S.; Punt, A.E. (1999). Experiences in the evaluation and implementation of management procedures. *ICES Journal of Marine Science 56:* 985–998.

Francis, R.I.C.C. (1999). Moving towards B_{MSY}. *New Zealand Fisheries Assessment Research Document 99/2.* 23 p. (Unpublished report held in NIWA library, Wellington).

Geromont, H.F.; De Oliveira, J.A.A.; Johnston, S.J.; Cunningham, C.L. (1999). Development and application of management procedures for fisheries in southern Africa. *ICES Journal of Marine Science 56:* 952–966.

McKoy, J.L. (1983). Movements of rock lobsters, *Jasus edwardsii* (Decapoda: Palinuridae), tagged near Stewart Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 17:* 357–366.

McKoy, J.L. (1985). Growth of tagged rock lobsters (*Jasus edwardsii*) near Stewart Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 19:* 457– 466.

Ovenden, J.R.; Brasher, D.J.; White, R.W.G. (1992). Mitochondrial DNA analysis of the red rock lobster *Jasus edwardsii* supports an apparent absence of population subdivision throughout Australasia. *Marine Biology 112(2):* 319–326.

Starr, P.J.; Bentley, N. (2002). Assessment of the NSS stock of red rock lobster (*Jasus edwardsii*) for 1999. *New Zealand Fisheries Assessment Report 2002/28.* 50 p.

Starr, P.J.; Breen, P.A.; Hilborn, R.; Kendrick, T.H. (1997). Evaluation of a management decision rule for a New Zealand rock lobster substock. *Marine and Freshwater Research 48(8):* 1093–1101.

Stokes, K.; Kearney, B.; Annala, J.H. (2001). Report on the "B_{MSY} Workshop". Unpublished report held by the Ministry of Fisheries, Wellington, New Zealand.

Street, R.J. (1973). Trends in the rock lobster fishery in southern New Zealand, 1970-1971. *New Zealand Fisheries Technical Report No. 116.* 32 p.

Street, R.J. (1995). Rock lobster migrations in southern New Zealand. *Seafood New Zealand 3(7):* 19–21.