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EXECUTIVE SUMMARY

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.

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Decision rules have become an important tool for managing New Zealand rock lobster (*Jasus edwardsii*) fisheries. In the past, the focus of decision rule application has been depleted stocks, for which the primary objective was to rebuild biomass. Decision rules may also be useful in fisheries that are not overexploited. We describe the development of alternative decision rules for stocks estimated to be above the legislated minimum biomass level.

This report does not attempt to provide recommendations on the most appropriate decision rule. Rather, the emphasis of this work was to solicit from stakeholders objectives for management of their fishery and to illustrate how trade-offs between those objectives need to be considered in the choice of a decision rule.

Quantifiable performance indicators are required for designing and evaluating decision rules. A workshop was held with representatives from the commercial, recreational, customary, and conservation sectors to agree on management objectives and associated performance indicators for these fisheries. Discussions emphasised trade-offs among objectives. For example, stability in catch quotas must be traded off against maximising long-term yield.

Objectives proposed by stakeholders included stability in catch quotas, maintenance of high abundance, and maintenance of a wide size range of lobsters so that fishers can respond to changes in market demand. Several decision rules were designed and evaluated with respect to the proposed objectives using stochastic simulations. The results illustrate that the ultimate choice of decision rule will depend upon the relative weight given to each objective.

1. INTRODUCTION

A decision rule is a procedure for making fisheries management decisions. It is often based on a response to easily monitored attributes of the stock, although it may also be based on the results of a stock assessment. Decision rules clarify management objectives and increase certainty in management by formalising the decision making process. Decision rules have also been named harvest control rules (e.g., Kell et al. 1999), management procedures (e.g. Witting 1999) and harvest algorithms (e.g., Cooke 1999).

The focus of rock lobster decision rule development and application in New Zealand has been depleted stocks where the primary concern is to rebuild the stock. Decision rules may also be useful for stocks estimated to be above the legislated objective of B_{MSY}. This report describes work done for Objective 8 of Ministry of Fisheries Project CRA1999/01: "to develop and evaluate decision rules for the NSN and NSC stocks". Both stocks are estimated to be above B_{MSY} and have existing decision rules based on comparing CPUE to a baseline 1992–93 level. The current CPUE is higher than the 1992–93 level and stakeholders wish to maintain it at about the current level.

This report does not attempt to provide recommendations on the most appropriate decision rule for either the NSN or NSC stock. Rather, the emphasis of this work was to solicit from stakeholders objectives for management of their fishery and to illustrate how trade-offs between those objectives should be considered in the choice of a decision rule.

2. MANAGEMENT OBJECTIVES AND TRADE-OFFS

To develop and evaluate decision rules, quantifiable management objectives need to be defined. The most appropriate rule will depend upon the particular objectives chosen for management. The primary management objective in legislation is the requirement for stocks to be maintained at or above B_{MSY}. As long as the fishery can be maintained above this level, there may be other management objectives which stakeholders wish to attain.

To define management objectives, a workshop was held with representatives from commercial, recreational, customary, and conservation sectors. The workshop aimed to identify the management objectives with which to design and evaluate decision rules for the NSN and NSC stocks.

Some ground rules set for workshop discussions were (a) that stakeholders were not bound to choices they made in the workshop, and (b) that objectives had to be consistent with existing legislation. To stimulate creative and positive discussion on management objectives, participants were asked to assume that catches from all sectors were known and that all stakeholders (including the Ministry of Fisheries) agreed to the decision rule management process. Participants were asked to focus on management objectives, not the practicalities of application of decision rules.

Stakeholders identified five management objectives (Table 1). These objectives were easily translated into quantitative performance indicators for evaluation of decision rules.

Discussions noted the potential trade-offs between these objectives. For example, taking higher catches leads to lower abundance, which will reduce CPUE. A rule that is more responsive to changes in the stock will produce higher yield, but will have more frequent changes in quota. A strategy which has a lower risk will usually have a lower yield. These trade-offs are very important in designing and evaluating decision rules. For instance, one decision rule may produce high catches but lead to lower abundance, another may result in higher abundance but lower catches; the choice between these two rules would depend upon the relative importance of each objective.

To evaluate decision rules it would be convenient if stakeholders could assign weights to each performance indicator. In the evaluation of decision rules, these weights could be combined to provide a single index of the performance of each rule. For example, a simple additive index can be used (Keeny 1977),

$$\bar{I} = \sum_{i=1}^{n} w_i I_i$$

where $\bar{I}$ is the overall performance indicator, I_i is the performance indicator for rule i and w_i is the weight for performance indicator i. This approach can be extended to the use of simplex diagrams to determine what combination of weighting results in the choice of different rules (Lane & Stephenson 1998).

While this simple approach is appealing, there are several problems with it. First, it is often difficult for stakeholders to decide on explicit quantitative weightings for each indicator. Stakeholders are not usually able to make statements such as "let us trade-off 100 t of annual catch for 0.75kg per potlift instead of 0.5 kg per potlift". This difficulty in weighting different objectives is largely due to the different scales of measurement (e.g., tonnes and kilograms per potlift). Secondly, the relative weighting for each indicator may not be constant over all levels of that indicator. For example, although the above trade-off may be attractive when catches are 1000 t, the sacrifice of 100 t catch from a catch of 200 t could be unacceptable. Finally, in additive weighting even a completely unacceptable level of one performance indicator (e.g., a risk of collapse of greater than 20%), may be completely masked by high values of other indicators.

To address these issues we used an alternative means of combining performance indicators. First, we re-scaled each indicator to represent an index from 0 to 1 in the range of values observed in the alternative decision rules tested. An index of 1 represents the best value of the management objective tested and an index of 0.5 represents half the best value. We ensure a positive relationship between the index and the management objective, i.e. the index increases as the objective is better met. Thus, we use "safety" rather than risk, where safety = 1 – risk).

Second, instead of assuming that the utility of the index is constant, we use a function to describe stakeholder preference for different values of an indicator. The function we use has two parameters easily understood by stakeholders: the minimum acceptable value below which utility is zero, m, and the value at which utility no longer increases, l,

$$U = \begin{cases} 0 & \dot{I} < m \\ \dfrac{\dot{I} - m}{l - m} & m < \dot{I} < l \\ 1 & \dot{I} > l \end{cases}$$

where $\dot{I}$ is the re-scaled index of the performance indicator. This function allows the expression of different types of objectives. For example, a pure 'maximisation' objective can be achieved by setting $m = 0, l = 1$. A pure 'threshold' objective can be achieved by setting $m = l$. Mixtures of these types can also be achieved.

To illustrate how these utility functions operate in the choice of an optimum decision rule, we established some example parameterisations for each performance indicator (Figure 1). For yield, abundance and safety, m was set so utility is zero from values less than 10%, 20%, and 80% of the maximum of these indicators respectively. For example, any rule with a risk of greater than 20% will have an overall utility of zero. Similarly, for stability and diversity an upper threshold was used, above which there is no additional benefit of higher values. In the example, the utility of quota changes once every ten years is no higher than changes once every five years.

Finally, we use a multiplicative model rather than additive method for combining the utilities from different performance indicators, $\overline{U}_j = \left(\prod_{i=1}^{n} U_{ij} \right)^{\frac{1}{n}}$

where n is the number of indices that are combined. If any index has a utility of zero because it is lower than the minimum acceptable level, the combined utility is zero. If all indices were at their maximum, then the combined utility would be one.

3. DECISION RULE DESIGNS

Two types of decision rule were tested in simulations (Table 2). These are not necessarily the best types of rules but rather serve to illustrate the potential variety of decision rules and their relative performance.

The first, which we call the "fixed" type, is focused on maintaining a target biomass of recruited lobsters. It is based on the presumption that we know what the best level of biomass is. Adjustments are then made in response to deviations in biomass from this target. The rule arbitrarily includes a 'latent' year so that changes in quota cannot be made in two successive years; this reduces the tendency to over-correct. The decision rule has three parameters, the number of years over which the running average of CPUE is taken, and trigger (T) and response (R) parameters. The testing algorithm is as follows:

1. Include the current year's index of CPUE in the running average.
2. If it is not a latent year, then calculate the ratio between the running average of CPUE ($\overline{C}$) and the target CPUE (C_t),

$$r = \frac{\overline{C}}{C_t}$$

3. If $r < 1 - T$ then reduce quota by a factor of $1 - R$ and make the following year a latent year. Otherwise if , $r > 1 + T$ then increase quota by a factor of $1 + R$ and make the following year a latent year. Otherwise make no change to quota.

The second rule type, which we call 'adaptive', acknowledges that a variety of tradeoffs need to be made and that there is uncertainty in the productivity of the stock. It is based upon monitoring indices of both pre-recruit and recruited biomass and adjusting quota accordingly. The number of pre-recruits (animals smaller than the minimum legal size limit) per potlift is used as an index of pre-recruit abundance.

Instead of focusing on one particular target, the rule takes an 'adaptive' approach to responding to changes in the stock. It does this by using the CPUE at the time that the last quota change was made as a reference point. This may be important if there are unpredictable changes in the productivity of the stock through ecosystem regime shifts or consistently lower or higher recruitment. The rule attempts to separate the change in vulnerable biomass in the stock into two parts: (a) that due to growth and mortality of recruited lobsters and (b) that due to recruitment. The rule has three parameters: the number of years over which the running average of CPUE is taken, the number of years over which the running average of pre-recruit abundance is taken, and a trigger (T).

The algorithm for the rule is:

1. Include the current year's index of CPUE and pre-recruit abundance in the running average for CPUE and pre-recruits respectively.
2. Calculate the ratio between the running average of CPUE ($\overline{C}$) and the CPUE the last time quota was changed (C_l) and adjust for any changes that may be due to changes in pre-recruit abundance.

$$r_c = \frac{\overline{C}}{C_l} - \frac{\overline{P}}{P_l}$$

To prevent negative values, if $r_c < 0.1$ then $r_c = 0.1$.

3. Calculate the ratio between the running average of pre-recruit abundance ($\overline{P}$) and the pre-recruit abundance the last time quota was changed (P_l),

$$r_p = \frac{\overline{P}}{P_l}$$

To prevent negative values, if $r_p < 0.1$ then $r_p = 0.1$.

4. Use a geometric mean to combine the two ratios into a single index of the change in the stock size since the last time that quota was changed,

$$r = \sqrt{r_p r_c}$$

5. If $r < 1 - T$ or if $r > 1 + T$ then reduce quota by a factor of r. Otherwise make no change to quota. If the quota is changed then both C_l and P_l are reset to their current values.

4. SIMULATION METHODS

For evaluating alternative decision rules we used the 1999 stock assessment for the northern (NSN) stock (Breen et al. 2001) as an operating model. The model was projected to 2050 using the two types of decision rule and 125 combinations of parameters for each type. These projections were repeated for each of 2500 samples from the joint posterior distribution of parameter estimates from the Breen et al. 2001 assessment. For the beginning of each simulation the commercial catch was set at 534 t. The illegal catch was assumed to be constant at 160 t for all simulations. Recruitment multipliers were randomly sampled from a lognormal distribution with a mean of 1 and a coefficient of variation of 0.4.

The predicted number of lobsters in the population, after taking into account the effects of vulnerability and pot selectivity, was used as a pre-recruit index. Observation error on both pre-recruit and CPUE indices was simulated using a lognormal distribution with a mean of one and a standard deviation of 0.3.

The 5 performance indicators shown in Table 1 were calculated based on values of catch, CPUE, vulnerable biomass and the predicted size distribution of the catch in each year. The numbers of lobsters in each 2mm tail width size bin were categorised into weight grades: A(0-0.6 kg), B (0.6-0.8 kg), C (0.8-1.0 kg), D (1.0-2.0 kg), E (2.0-2.5 kg), and F (>2.5 kg).

5. RESULTS

For some pairs of performance indicators there is a trade-off. For example, increased safety comes at the cost of reduced yield (Figure 2). There is a "choice frontier" where for a given level of one indicator, the other is maximised. This can be considered as a frontier because at the given level of one performance indicator, higher values of the other are not possible given the dynamics of the stock and the decision rule type tested. Given only two performance indicators, a choice of decision rule not on the frontier would be irrational. But which place on the frontier stakeholders choose depends on the relative weighting given to each objective.

If safety and yield are given equal weighting, the highest utility occurs at a relatively low yield (Point A, Figure 2). If stakeholders place twice as much weight on yield, the highest utility is from a decision rule with very low safety (Point B, Figure 2). As a compromise, stakeholders might use the equal weighting but change the utility function for safety to be zero at less than 80% safety (Point C, Figure 2). This is equivalent to setting $m = 0.8, l = 1$ in the utility function described above.

In reality the evaluation of decision rules is far more complex because there are usually several performance indicators. Consequently, a matrix of tradeoffs need to be made between the objectives that each indicator represents. In some instances there is little or no trade-off between objectives. This occurs objectives are positively correlated (e.g. abundance v. safety). In general the largest trade-offs are between yield and the other objectives (Figure 3). The adaptive type of decision rule usually performed better than the fixed type. For example, for a given level of safety the adaptive type rules usually provided greater long term yield (lower-left box, Figure 3).

Using the example utility functions described previously, the optimum decision rule type and parameterisation was the adaptive rule with a one year running average of pre-recruit abundance, a 2-year running average of recruited abundance (CPUE), triggered when the percentage change in the calculated indicator is 50% or greater. The highest value of the percentage change parameter tested was 50%; higher values may have performed better. Examples of the relationship between this particular rule and other parameterisations are shown in Figure 4.

This choice of optimum rule is dependent upon the utility functions that were used and serves only as an example of the processes involved in choosing between alternative rules.

6. DISCUSSION

This work has considered the trade-offs between management objectives when evaluating alternative decision rules. The decision rules considered here and in previous evaluations for New Zealand rock lobster fisheries (Starr et al. 1997) include only one management parameter – total allowable catch. In reality other management parameters could be varied; these include the minimum legal size, pot escape gaps, stock definitions, spatial and temporal closures and the extent of monitoring. These parameters are less suitable than total allowable catch for frequent changes under a decision rule. However, the most appropriate combination of these management parameters could be evaluated in a similar manner using management strategy evaluation (e.g. Punt & Smith 1999). The concepts described in this report regarding trading off management objectives can also be applied to management strategy evaluation.

The design and evaluation of decision rules requires quantitative definitions of management objectives. This study began by soliciting management objectives from stakeholders in New Zealand rock lobster fisheries. Although these were obtained, it was difficult for stakeholders to place relative weightings on each objective. These weights are important because of the trade-offs that often exist between objectives.

The weighting of objectives should be defined by stakeholders, not fisheries scientists. This report describes a method for weighting management objectives that is likely to be intuitive to stakeholders. However, it still requires some explicit statement of the weight between management objectives. Methods for choosing between decision rules and management strategies that avoid having to define such weightings may be preferable.

7. ACKNOWLEDGMENTS

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Table 1: Management objectives identified by stakeholders, related performance indicators, and method of scaling.

Name	Objective	Performance indicator (I)	Scaling method ($\dot{I}$)
Abundance	Maintain high abundance – there are economic, biological, and social benefits of high catch rates	Mean of CPUE (kg per potlift)	I/max (I)
Diversity	Maintain a wide size range of lobsters – fishers are able to respond to changes in market demand	Mean of the Shannon diversity index of numbers in each of four marketing size grades	I/max (I)
Stability	Minimise frequency of quota adjustments – a maximum of 3 to 5 years is preferred	Frequency of quota adjustments	1 - I
Safety	Minimise risk of very low biomass levels	Probability of stock falling below 10% of virgin biomass	1 - I
Yield	Maximise catch	Mean annual catch	I/max (I)

Table 2: Rationale, description, and parameters for the two types of decision rule that were evaluated.

Rule type	Fixed	Adaptive
Rationale	A certain biomass level is optimal so adjust quota in response to CPUE deviations from corresponding target.	A variety of trade-offs between objectives need to be made. There is uncertainty in the optimal biomass level and the productivity of stock. Adapt to changes in the stock.
Description	Decrease quotas if they fall below target, increase quotas if they rise above target.	Monitor pre-recruit and recruited abundance. If recruitment is lower than average, and/or recruited biomass is independently falling, decrease quota and vice verse.
Parameters	*Years*: numbers of years to take running mean of CPUE (1–5) *Trigger*: percentage change in CPUE that causes a change in quota (10–50%) *Response*: percentage change in quota when triggered (10–50%)	*Pre-recruit years*: numbers of years to take running mean of pre-recruit abundance (1–5) *CPUE years*: numbers of years to take running mean of CPUE (1–5) *Trigger*: percentage change in indicator that causes a change in quota (10–50%)

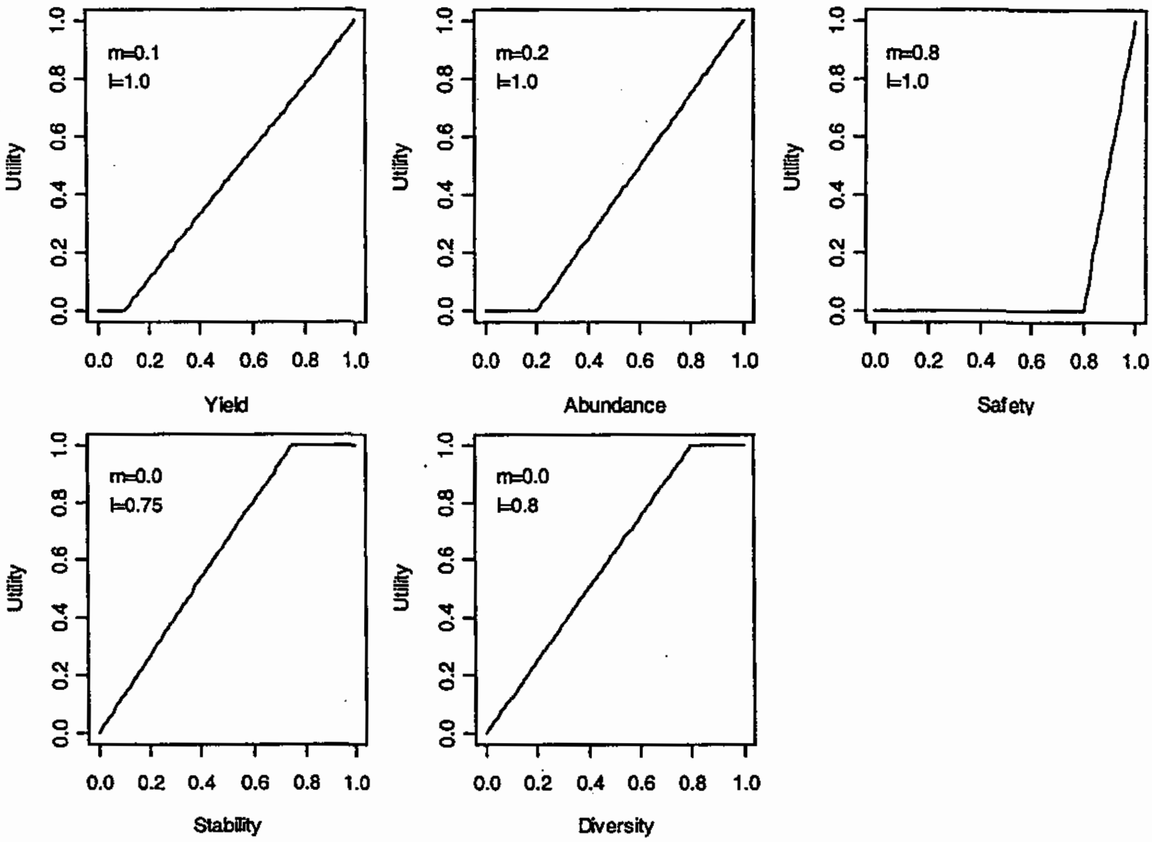

Figure 1. Examples of utility functions for each management objective.

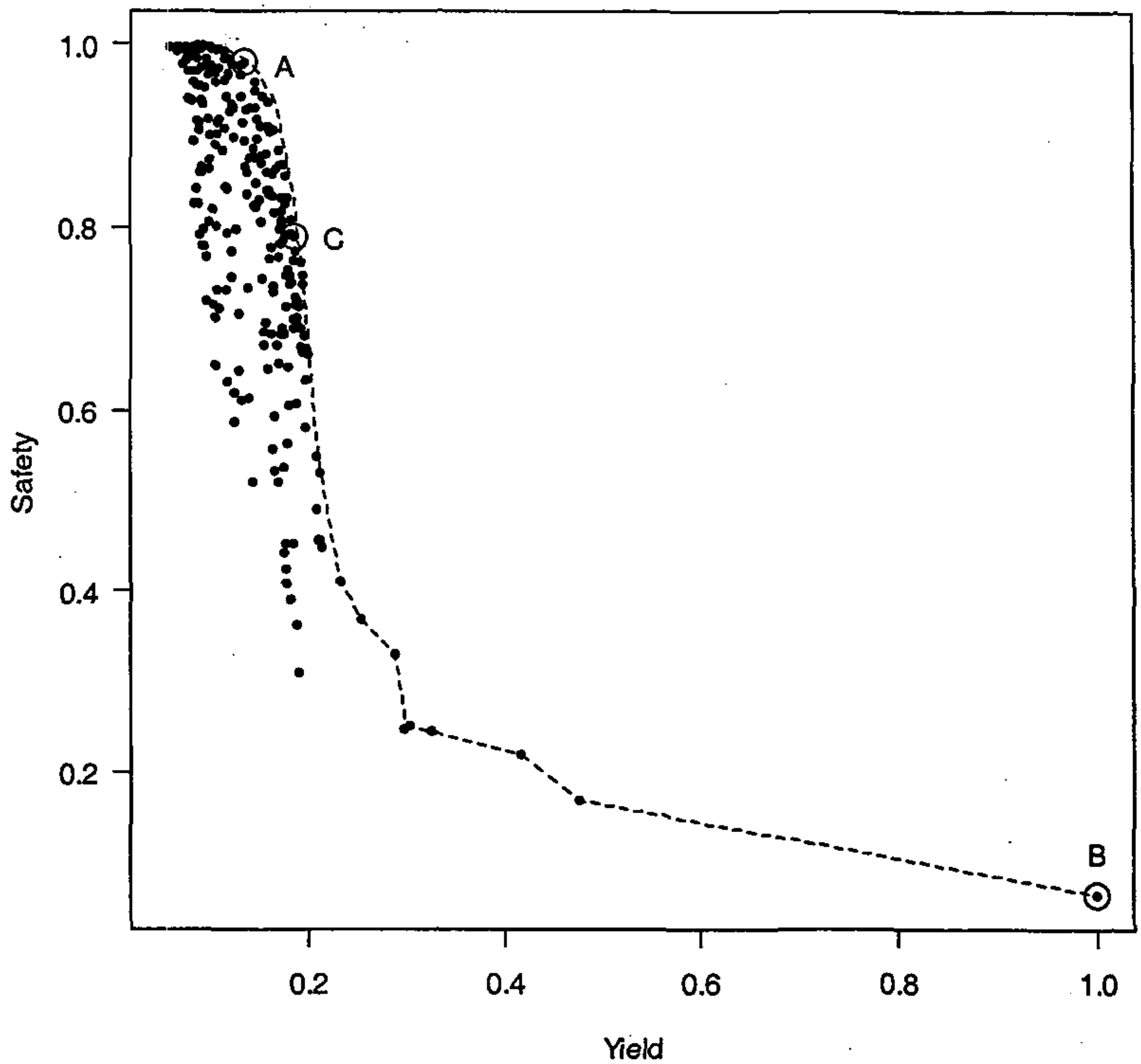

Figure 2: An example of a trade-off between management objectives. Each point represents the one of the 250 decision rules that were tested and is located at the median of the two performance indicators from the 2500 samples of the posterior distribution. Dashed line indicates the choice frontier: the maximum yield for a given level of safety and *vice verse*. Circles indicate choices made with alternative weightings of objectives (see text for details).

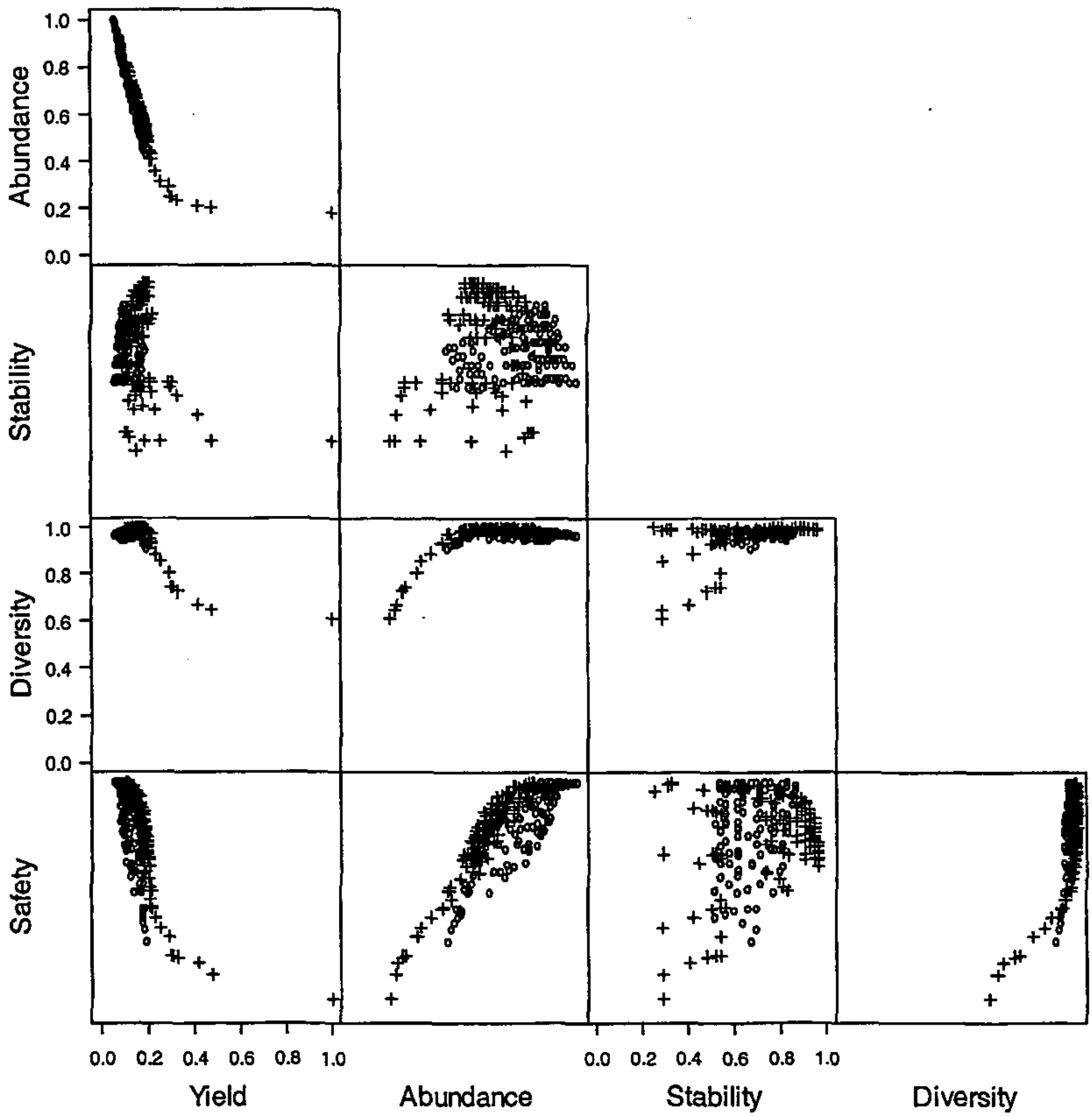

Figure 3: Trade-off matrix for management objectives for the types and parameterisations of decision rules examined. As in Figure 2 each point represents one of the decision rules tested: open circles: fixed type; crosses: adaptive type.

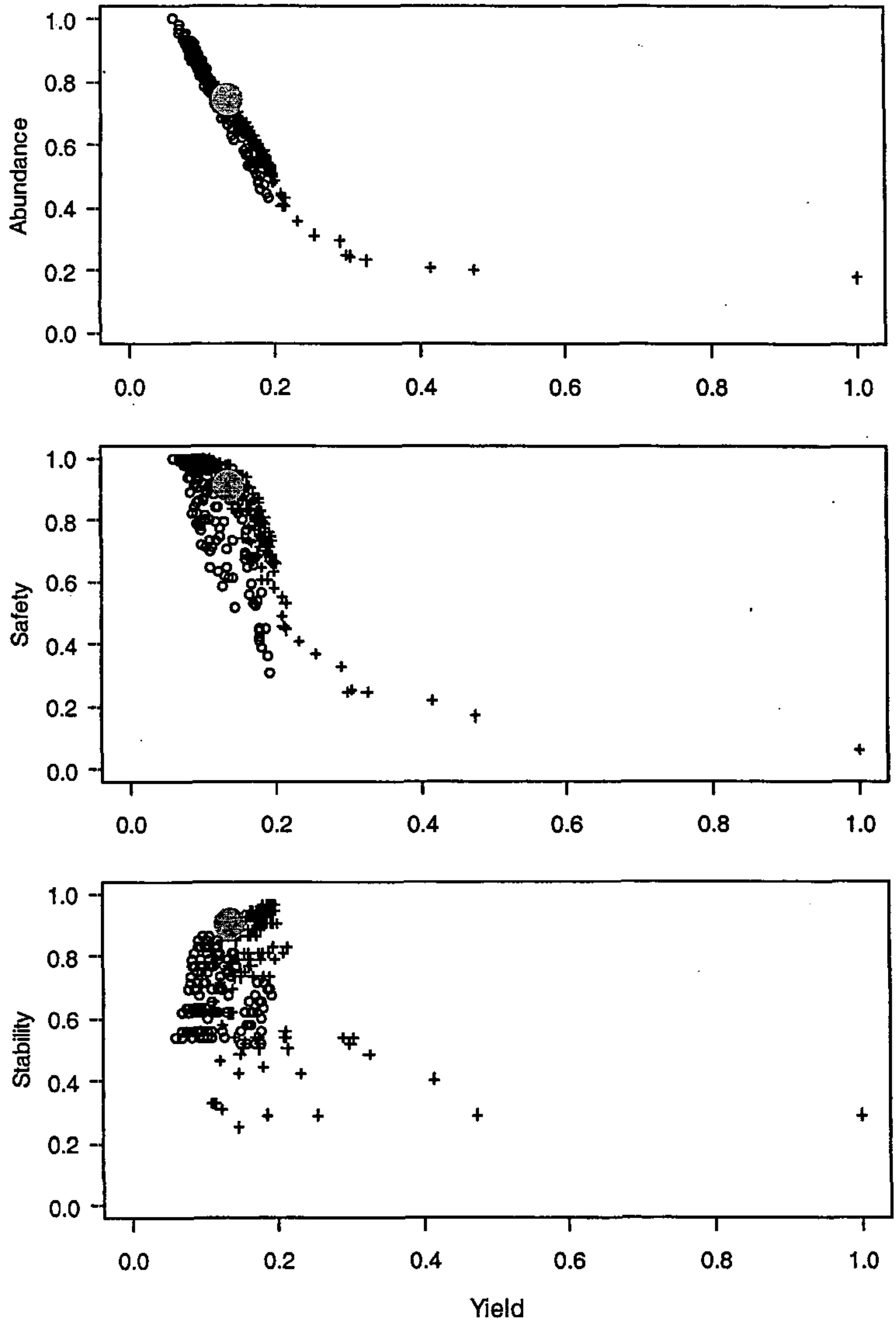

Figure 4: The optimum choice of decision rule (large filled circle) based on the utility functions shown in Figure 1. Open circles: fixed type; Crosses: adaptive type.